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OPERATION OF DYNAMOS AND MOTORS
ELECTRIC RAILWAYS

SCRANTON:
INTERNATIONAL TEXTBOOK COMPANY
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PREFACE

The International Library of Technology is the outgrowth of a large and increasing demand that has arisen for the Reference Libraries of the International Correspondence Schools on the part of those who are not students of the Schools. As the volumes composing this Library are all printed from the same plates used in printing the Reference Libraries above mentioned, a few words are necessary regarding the scope and purpose of the instruction imparted to the students of—and the class of students taught by—these Schools, in order to afford a clear understanding of their salient and unique features.

The only requirement for admission to any of the courses offered by the International Correspondence Schools is that the applicant shall be able to read the English language and to write it sufficiently well to make his written answers to the questions asked him intelligible. Each course is complete in itself, and no textbooks are required other than those prepared by the Schools for the particular course selected. The students themselves are from every class, trade, and profession and from every country; they are, almost without exception, busily engaged in some vocation, and can spare but little time for study, and that usually outside of their regular working hours. The information desired is such as can be immediately applied in practice, so that the student may be enabled to exchange his present vocation for a more congenial one or to rise to a higher level in the one he now pursues. Furthermore, he wishes to obtain a good working knowledge of the subjects treated in the shortest time and in the most direct manner possible.

In meeting these requirements, we have produced a set of books that in many respects, and particularly in the general plan followed, are absolutely unique. In the majority of subjects treated the knowledge of mathematics required is limited to the simplest principles of arithmetic and mensuration, and in no case is any greater knowledge of mathematics needed than the simplest elementary principles of algebra, geometry, and trigonometry, with a thorough, practical acquaintance with the use of the logarithmic table. To effect this result, derivations of rules and formulas are omitted, but thorough and complete instructions are given regarding how, when, and under what circumstances any particular rule, formula, or process should be applied; and whenever possible one or more examples, such as would be likely to arise in actual practice—together with their solutions—are given to illustrate and explain its application.

In preparing these textbooks, it has been our constant endeavor to view the matter from the student's standpoint, and to try and anticipate everything that would cause him trouble. The utmost pains have been taken to avoid and correct any and all ambiguous expressions—both those due to faulty rhetoric and those due to insufficiency of statement or explanation. As the best way to make a statement, explanation, or description clear is to give a picture or a diagram in connection with it, illustrations have been used almost without limit. The illustrations have in all cases been adapted to the requirements of the text, and projections and sections or outline, partially shaded, or full-shaded perspectives have been used, according to which will best produce the desired results. Half-tones have been used rather sparingly, except in those cases where the general effect is desired rather than the actual details.

It is obvious that books prepared along the lines mentioned must not only be clear and concise beyond anything heretofore attempted, but they must also possess unequaled value for reference purposes. They not only give the maximum of information in a minimum space, but this information is so ingeniously arranged and correlated, and the indexes are so full and complete, that it can at once be made available to the reader. The numerous examples and explanatory remarks, together with the absence of long demonstrations and abstruse mathematical calculations, are of great assistance in helping one to select the proper formula, method, or process and in teaching him how and when it should be used.

The greater part of this volume is devoted to electric railways. In addition there is a section on the practical operation of dynamos and motors, which includes a great many valuable hints regarding the operation of machines, locating and remedying faults, and numerous other practical points. The subject of Electric Railways is taken up in an unusually comprehensive manner; all the systems of operation are explained, and every detail, even to the heating and lighting appliances on the cars, is taken up. Car-wiring diagrams and car equipments generally are treated in a manner unapproached by other textbooks, particular pains having been taken to produce a set of car-wiring diagrams complete in every respect, with the result that they are far clearer than those hitherto published. Special attention is paid to the various methods of speed control and diagrams are given for all the most important outfits. Numerous styles of track and line construction are illustrated, so that the kind best suited to any particular case can be readily selected.

The method of numbering the pages, cuts, articles, etc. is such that each subject or part, when the subject is divided into two or more parts, is complete in itself; hence, in order to make the index intelligible, it was necessary to give each subject or part a number. This number is placed at the top of each page, on the headline, opposite the page number; and to distinguish it from the page number it is preceded by the printer's section mark (§). Consequently, a reference such as § 16, page 26, will be readily found by looking along the inside edges of the headlines until § 16 is found, and then through § 16 until page 26 is found.

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ELECTRIC RAILWAYS—*Continued*

OPERATION OF DYNAMOS AND MOTORS.

INSTALLATION.

1. Location.—The location of a large dynamo or motor is a matter generally determined by local surroundings; that is, the position of the dynamo depends on where its engine may be, and the disposition of the motor depends on what it is to drive and where it is located. Assuming, however, that the conditions are such that the selection of a site for the dynamo or motor is not hampered by other considerations than that the machine shall be put in a place best adapted to itself, the following points should be kept in mind: It should be kept in a clean, dry, cool place, out of reach of drippings from steam and water pipes, and protected from dropping of water due to the condensation that sometimes takes place on an iron roof. The machine should preferably be placed where there can be a draft of air across it from windows or doors on opposite sides, and in such cases, if it is located on the ground floor, there should be ample means for sprinkling the street in the vicinity to keep down the clouds of dust that are otherwise sure to be present in dry weather. This precaution will permit a free circulation of air when it is most needed—in the hot summer months.

The space surrounding the machine should be clean and free from all obstructions. Where the machine is controlled from a switchboard, a man should be able to go from one to the other without going through a belt or past a number of obstructions. Dust from the street is injurious to the commutator, bearings, and general insulation of electrical machines, but dust from a coal pile or any kind of grinding or turning machine is even more so; therefore, the engine and dynamo rooms should be protected from the dust incidental to coal handling, and no emery wheels, grinders, speed lathes, etc. should be allowed in the room. Where motors are installed in rolling mills, forge rooms, carbon works, or places where a great deal of power grinding or finishing is done, the motor should be of an enclosed type, its bearings should be protected, just as those of a grinder are, and the machine should be properly caged.

2. Foundations.—Every machine of 25 horsepower, or more, should be provided with a substantial foundation, and this foundation should, if possible, be independent of the floor and walls of the building in which it is installed, to avoid communicating to them the very disagreeable vibration incidental to the running of the machinery. Where there are several machines to be installed, the idea is best carried out by having the whole floor space subconcreted and capped with a layer of cement or a wood floor. Where a single machine is to be installed, it is sufficient to limit the foundation to a little more than its floor area. In any case, solid brickwork is the best foundation, but where its use is impracticable, a substantial wooden frame construction can be used. Even where the concrete or brick foundation is used, it is customary to cap this with a hardwood frame, served with a high-grade insulating compound of some sort; the layer of wood serves not only to insulate the metal frame of the machine from the ground, but it acts as a cushion to take up the blows and vibration. The insulation feature must not be defeated by having the bolts that secure the wood frame to the masonry come in contact with those that secure the metal frame of the machine to the wood.

No rule in regard to the depth of the foundation can be given to cover all cases, as the subsoil is so different in different places. In one section, bed rock will be found a few feet from the surface, while in another section of the country it will be necessary to drive piles to support the foundations for the heavier machines. Fig. 1 shows a style of foundation very much used; the foundation proper is made of brick laid with 1 part of the best cement to 2 parts of good, sharp sand. The surplus of excavation is filled in with a mixture of broken stone and cement, which is capped to a surface with pure cement. The masonry is built around the anchor bolts.

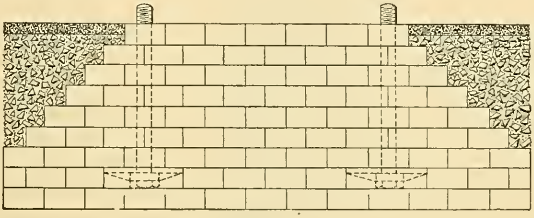


Fig. 1.

Wherever the machine is to be belt-driven, means should be provided for tightening or slacking the belt. On most machines this is usually accomplished by screws or by mounting the machine on rails or on a subbase and moving the machine by means of a ratchet lever and screw. As an example of this we may take the machine shown in Fig. 2. The foundation should in every case be so disposed that the distance between the driving and driven centers will allow one side of the belt to run looser than the other. This distance should be at least four times the diameter of the larger pulley.

3. Erection.—Small machines are, as a rule, shipped complete and ready to run, so that there is nothing to do but to put them in place, put the pulley on, and line them up. Large machines cannot be shipped with safety in an assembled condition, and some are so large that they could not be gotten through the door of a closed car; so they are dismounted and the parts marked and packed in separate parcels. It then falls upon the roadman or the purchaser to assemble them at their destination. This work should not be undertaken by one not familiar with such work, and even an expert should not be above consulting the blueprints and the marks on the parts.

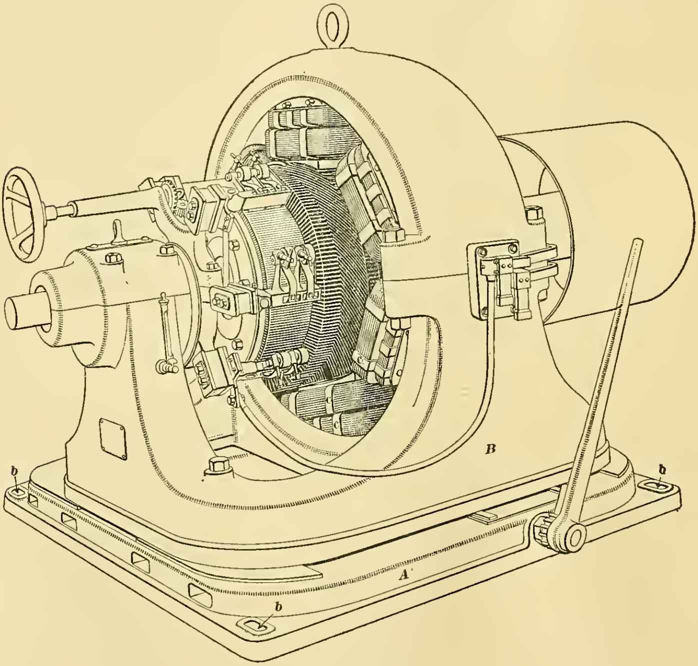


FIG. 2.

No man should try to assemble the parts of a heavy machine without being provided with the rigging devices adapted to the work. Large stations provided with large units are generally equipped with cranes to replace armatures or fields that may become burned out. Small stations are not so well fixed, so the installer must usually look them up for himself. As the construction of machines varies to some extent, so must the method of handling the parts. In order to be specific, the machine shown in Fig. 2 will be taken as the one to be assembled. This is a six-pole belt-driven street-railway generator of the Westinghouse type. The bedplate *A* and the lower half of the machine *B* are worked on to the foundation by means of crowbars and rollers; as the wooden sub-frame projects above the level of the floor, a false wood floor must sometimes be laid. The bedplate is then worked into such a position that the holes *b*, *b* in the four corners of the foot flange fall just over the bolts or bolt holes that they are intended to engage. The blocking is then taken out and the machine let down upon the foundation or frame, as the case may be.

4. The next step is to place in position and connect together the bottom field coils *c*, *c*; the field coils may be put in the top half of the frame at the same time, so that this part can be swung into position as soon as the armature is in place. Great care must be taken that the coils are slipped over the pole pieces with proper regard for the marked ends, or trouble will surely result. Field coils that do not weigh more than 200 pounds may be safely lifted into place, but great care must be taken not to bruise the insulation or bend or break the terminals. For handling heavier coils than this, and also for handling the armature and top half of the frame, tackle must be rigged immediately above the foundation. In rigging this tackle, the total height that the top half of the frame must be lifted to get it in place after the armature is in position must be considered. If a chain hoist must be used, do not attempt to lift a 4,000-pound armature or top field half with a 2,000-pound hoist—use a 4,000-pound hoist, or even two 2,000-pound hoists. To support the hoist, a rope is slung in several turns from a roof girder or from a crosspiece laid between two girders. Old cloth or carpet is interposed between the rope and the girder so that the former may run no chance of being cut. The hoist is hung at such a height as will enable its full hoisting range to be utilized. If in spite of all that can be done, the hoist does not have sufficient range for the highest lift, the lift will have to be divided into two stages. These two stages must be such that the end of the first lift leaves the part to be lifted as near to the floor as possible. The part is then securely blocked, the point of support of the hoist raised, and the lift completed. To put the armature in place, it is moved as close as possible to the machine, so that its tendency to swing in, due to its being out of the vertical line of the hoist, will be a minimum. This tendency must be further offset by means of a strain put on by a block and tackle or hand line applied at the side. The bearing parts of the armature shaft should be encased in cloth before lifting, to avoid nicks and dents. The pillow-blocks should be inspected to see that they contain no iron filings or other dirt, and should then be filled with a good quality of oil.

5. Under no circumstances should any of the weight of the armature be supported by any device in contact with the commutator; the point of support should always be the shaft. For handling small armatures whose pillow-blocks are removable, a couple of ordinary handle bars, such as those shown in Fig. 3, should be used, and for the heavier ones a rope sling *S* and spread bar *B* such as are shown in Fig. 4; note that the rope is crossed on itself when it passes through the hook. When handling a heavy armature, its commutator should be protected by a blanket or other padding to save it from knocks that may dent a bar or damage

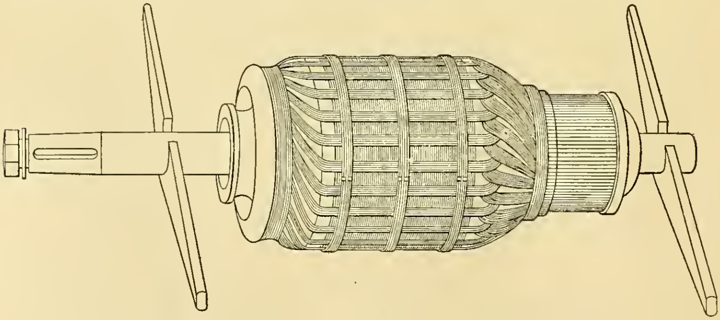


FIG. 3.

a band; the armature should not be rolled over the floor carelessly, as a nail head or a piece of hard matter of any kind in its path is liable to nick a band wire, so that as soon as the machine is up to speed and heated, causing some expansion, the band wire will break. As soon as the armature is swung over its final position, the shaft is wiped off with clean waste and served with a thin film of good cylinder oil. The bearings are then slipped on; in doing this, the oil rings must be lifted by running a clean round rod or stick in the end, otherwise the end of the shaft may jam one of the rings and bend or break it. Where spiral bearings are used, care must be taken to put them on the shaft as the marks call for, otherwise the oil will be fed out instead of in, and the box will run hot. All these points being looked after, the armature is dropped into place and given a few turns by hand to see that the oil rings work and that there is enough end play to prevent binding. Using the pulley end of the shaft as a straightedge, the machine is now leveled by means of a spirit level, split sheet-iron washers being put under the bedplate around the anchor bolts if one end must be raised.

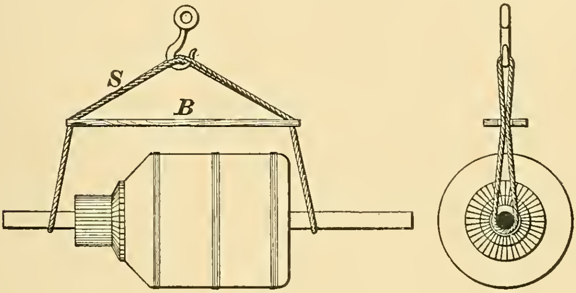


FIG. 4.

6. If the foundation and frame have been well made, little or no lining will be called for. With the armature in place, the top half of the frame, whose field coils have been previously connected, is lifted on. The joint between the top and bottom halves should be well cleaned before setting them together; it may be necessary to wipe off some white lead, put there to prevent rust, or to surface down a dent due to a falling tool. Where the machine has detachable pole pieces, the same care should be exercised in regard to the surfaces between them and their seats on the frame. When the top half is in place, the pulley is put on, the machine lined up to the engine that is to drive it or to the pulley that it is to drive, and the yoke, brush holders, and other fittings put on. The driving belt should have a cemented, not a laced, joint. It must be borne in mind that in order to make a good job of lining up the motor or dynamo, it is necessary that the device to which it is to be belted has been installed with the same care as the dynamo itself.

7. Starting Up.—If the machine is a dynamo, it is, of course, started up by means of its engine; if a motor, current from the line must be used. In either case, be sure that there are no tools or other parts lying on the belt or on the dynamo where they can shake off on to the armature or be sucked up by the fields. The machine should be run at about half speed for an hour or more to give bad bearings a chance to show their presence and to see that the oil rings do not stick. If all the parts of the machine seem to be in good working order, the speed can be run up to its normal rate, and the machine given a chance to pick up its field, but no load should be put on for several hours. Where the parts of a machine have been exposed and are damp, the insulation will be low, and arrangements should be made to bake the windings with current at low voltage, so that there may be no risk of a burn-out at the start; but in testing the insulation of a machine that is running on a grounded circuit, such as a street-railway circuit, unless the permanent ground is removed, the insulation will, of course, show a dead ground.

8. The machine should be turned over very slowly at first, so that in case it is not lined up exactly right the belt will not run off before the necessary change can be made; should the belt try to come off, it can, as a rule, be held on with a bar until the machine can be stopped; even if the belt does come off on the *outside* of the pulley, no special harm is done; but if it comes off *inside* of the pulley, it is liable to have one of its edges curled and stretched and it will give constant trouble afterwards. On this account, it is a good plan, if there is any doubt as to whether the pulleys are in line, to cant the machine pulley a little in favor of the outer edge.

9. In order for a dynamo to pick up its field, it is necessary that the fields have a little residual magnetism left over from the last charge. Electric machines, except some of the largest sizes, are always tested under load before they leave the factory, and, as a rule, retain enough of the magnetism to "pick up" on when they are installed. But sometimes on the way from the factory to their destination this magnetism is not only vibrated out of them, but in some cases the vibration has been known to reverse the polarity of the dynamos. Even machines in service a long time lose or reverse their residual magnetism for no apparent reason. In such cases, the fields must be recharged. In the case of an isolated machine, this recharging must be done from a battery, unless there is some other machine in the neighborhood that can be temporarily tapped to the outside line; where there is more than one machine, the field of the dead one can be charged from the live one; in such a case, the field leads must be either disconnected or the brushes lifted off the commutator of the dead one, to avoid running it as a motor. Of course, in the case of a motor, the field current is supplied from the line, so that with motors there is no trouble on account of the fields losing their magnetism.

OPERATION.

10. General Care of the Machinery.—The dynamo or motor and all devices connected with its operation or regulation should be kept perfectly clean. No copper or carbon dust should be allowed to accumulate to cause breakdowns in insulation. The oil gauges and grooves should be kept in working order and the oil in the wells should be renewed at regular intervals. The brushes should be kept clean. They should be set and trimmed to fit the commutator, and copper brushes should be taken out once in a while, whenever they become clogged, and dipped in gasoline to cleanse them. When a machine is shut down, copper brushes should always be lifted just before the dynamo comes to a stop and they should not be let down until the machine, if a dynamo, is under headway again. New carbon brushes should be sandpapered to fit the commutator, by sliding a piece of sandpaper back and forth between them and the commutator. Do not use emery paper for cleaning the commutator, as emery is more or less of a conductor and may cause short-circuiting between the bars; also small pieces of emery become lodged in the brushes and scratch the commutator. The connections and all setscrews and bolts should be inspected regularly to see that none are liable to become loose and fall out. All screws that secure shunt-field or rheostat wires should be fixed by a drop of solder.

Oil should be used very sparingly, if at all, on the commutator; to lubricate it, put a film of vaseline on a canvas cloth, fold the cloth once, and let the commutator get only what goes through the pores. Never allow a loose article of any kind to lie on any part of a machine. Oil cans should be made of brass so that they will not be attracted by the pole pieces. Do not allow a belt to run tight enough to cause a hot box, nor let it run so loose as to squeak and threaten to come off. When closing a switch, do not tap it in to see if everything is all right, but once the mind is made up that everything is as it should be, close the switch firmly. The operator's eyes and hands are of more importance and value than anything else in the station. If there is any doubt about whether a switch should be closed or not, do not close it until all doubt is removed. All switches should be left open when the machine is not in action. Circuit-breakers should be tried at frequent intervals to see that they are not stuck or set for the wrong load.

BRUSHES.

11. On direct-current machines, the brushes and commutator require, perhaps, more attention than all the other parts of the machine put together. Brushes should in the first place be of sufficient size to carry the full-load current of the machine without heating. Brushes are of two kinds: *radial* and *tangential;* **radial brushes** point straight at the center of the circle that represents the outline of the commutator; their direction is parallel to the radius, as shown in Fig. 5 (*a*). **Tangential brushes,** Fig. 5 (*b*), are generally made of copper and are found, as a rule, on lighting machines. Radial brushes are made of carbon and are mostly found on power machines, though they are now largely used on lighting machines as well. Carbon brushes are used on machines whose output is at a comparatively high voltage, and, hence, low current; copper brushes, on machines of high current and low voltage. Also, carbon radial brushes are used on machines that must admit of being reversed in rotation. Carbon brushes are generally found on machines subjected to sudden and violent variations of load, while copper brushes are better adapted to conditions of slowly varying or constant load. Carbon brushes are usually copper plated to within $\frac{1}{4}$ inch or $\frac{1}{2}$ inch of their bearing ends, in order to give them better contact with the brush holders. Also, carbon brushes often contain a lubricant in the form of the paraffin with which the carbon dust is treated in the course of its manufacture, so that these brushes being self-lubricating, no compound or grease is needed on the commutator itself. With carbon brushes, the commutator takes on a dark-chocolate polish and the brushes emit a squeaking noise at starting or stopping.

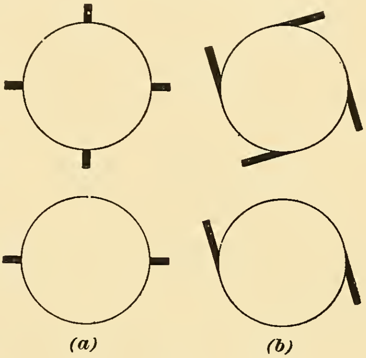


FIG. 5.

12. Carbon brushes are made in several grades of hardness, adapted to different conditions of working and different kinds of commutators. In stationary, direct-current work, soft carbon is used; on street-car work, hard carbon. Carbon has the great advantage that, being of relatively high resistance, it limits the value of the current generated in the coils that are short-circuited as they pass under the brushes and thereby reduces the sparking. By reason of this fact, carbon brushes admit of a wide variation in the load and hence in their non-sparking positions, without giving any trouble. This is why carbon brushes are used on high-voltage dynamos where there are sudden and violent changes that cannot be met by shifting the brushes. With copper brushes it is different; copper is of such low resistance that the short-circuited coil passing under a brush generates sufficient voltage to force a large current that causes sparking through the local circuit comprising the coil, two commutator bars, and the brush. This condition occurs if a variation in the load leaves the brushes out of the non-sparking points, so that copper brushes must, as a rule, be shifted to meet any variations in the load. Many kinds of copper brushes have been devised to meet this objection; in every case the object has been to increase the resistance in the path of the short-circuited coil without increasing the resistance to be traversed by the main current of the machine. To this end, brushes have been made of alternate layers of copper and of carbon, or have been made of copper wires or gauze.

In Fig. 6, *A* is the ring armature of a dynamo sending a current through lamps *L* by way of brushes $a+$, $a-$; coils *c*, *c* are passing under the brushes and are, therefore, being short-circuited by them through the local loops, *1–2–3–4–5–6–7*. It is not hard to see that if the center of the brush throughout its width be made of an insulating material, as indicated by the dotted lines, the local current due to the short-circuited coil cannot get from the heel of the brush to the toe, or *vice versa*, without first flowing up and down the full length of the brush, so that the short-circuited coil cannot generate so large a current, although the flow of the current in the main circuit of armature and lamps is not interrupted. On account of its decreasing the capacity of the brush, and for other reasons, it is not desirable to break the short local circuit, but a compromise is made by constructing the brush of alternate layers of copper and carbon or some metal whose specific resistance is high enough to reduce the current in the short-circuited coil, but not high enough to offer any serious impediment to the flow of the main current. Copper brushes are never made solid; they are made flexible, in one way or another, so that they may more readily conform to the surface of the commutator and bear at as many points as possible.

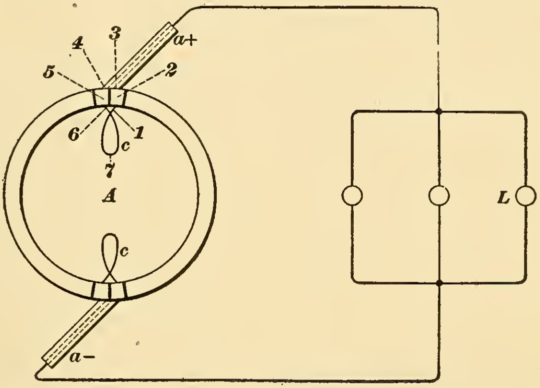


FIG. 6.

13. Ordinary copper brushes are not strictly tangential, this type being used only on small machines and on arc-light machines where the current is small. A form of strictly tangential brush is shown in Fig. 7 (*a*). Carbon brushes are often made as a kind of compromise between the tangential and the radial types, as shown in Fig. 7 (*b*). Just as in the case of the most common form of copper brush, it is neither exactly perpendicular nor parallel to a radius of the circle representing the end view of the commutator. No matter what style of brush is used, it should bear against the commutator with the proper tension. All generator brushes and stationary-motor brushes are so arranged that the tension can be regulated. Portable motors (street-railway motors) are not so fortunate. They are so limited in point of space and accessibility that the brush-holding device must be designed to average the right tension throughout the life of the brush.

The tension that a brush spring must have depends on the material and condition of the commutator and on the material of the brush itself. A copper brush does not, as a rule, call for as much tension as a carbon brush, and soft carbon will run with less tension than hard carbon; a rough commutator needs more brush tension than a smooth one; for given brush contact, large currents call for more pressure than small ones. Finally, where there are several brushes in each holder, the tension must be the same on all, so that they will all take about the same current. This tension should be great enough to pass the current without sparking or heating, but it should not be great enough to wear out the commutator unnecessarily. One of the features most conducive to success with brushes is the proper setting of them; this subject will be taken up in the article on "Sparking."

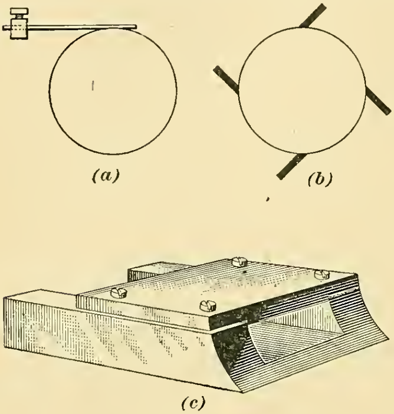


Fig. 7.

If the contact between the brush and the commutator is loose, the contact resistance will be high and heating will result. On the other hand, increasing the pressure beyond a certain amount results in very little reduction of resistance, but greatly increases the friction. For stationary work, a pressure of 2 to $2\frac{1}{2}$ pounds per square inch of brush contact surface should be sufficient. For railway work, the pressure has to be much heavier on account of the jarring to which the motor is subjected.

14. One of the greatest weaknesses of carbon brushes is that they, at times, stick in the holder so that the tension spring is not strong enough to force down the brush to its place, and even if it does force it down, the pressure on the commutator will be too light. This very serious fault may be due to either of two causes: lack of uniformity in the thickness of the brush or an excess of paraffin in the brush. If a brush is thicker at one end than it is at the other, it may go into the holder freely if put in thin end first, and might not go in at all on the thick end. The result of this is that as soon as the brush wears down to a point where the thick end enters the holder it sticks. On the other hand, the fault may be due to a nick or burr in the brush holder itself. The only way to get rid of all chance of such trouble is to have a hard-steel gauge for the brushes and another for the holders; discard all brushes that will not pass through the brush gauge freely and file out any holder that will not take the holder plug gauge. As a final check against a bad brush getting into use, always try the brush in the holder end for end. The common practice of sandpapering a brush to get it in is a very bad one, as it not only makes the brush lopsided, thereby impairing its contact with the main surface in the holder, but it also takes off the copper plating.

The second source of trouble—an excess of paraffin in the brush—is accounted for as follows: If a carbon brush is snugly fitted into the holder so that it slides back and forth freely, but without any clearance, while the holder and brush are cold, as soon as they become warm the paraffin oozes out, forms a paste with whatever carbon or copper dust there may be present, and causes the brush to stick. It is a very common occurrence to see brushes that have been giving trouble coated with a tough skin of carbon dust and paraffin that can be readily scraped off with a knife. It is very essential that the brushes should be kept clean and trimmed to fit the commutator; to trim them, an iron jig similar to that shown in Fig. 7 (*c*) should be used so that the bevel may be kept perfectly true. This jig is intended more particularly for filing copper brushes. Carbon brushes can be sandpapered to shape in place.

THE COMMUTATOR.

15. The **commutator** is the most sensitive part of a machine and its faults are liable to develop more quickly than those of any other part. When a commutator is in the best possible condition, it becomes a dark-chocolate color, is smooth, or glazed, to the touch, and causes the brushes, if of carbon, to emit a characteristic, squeaky noise when the machine is turning slowly. Under no circumstances should any weight be allowed to rest upon the commutator, nor should it be caught with a sling when the armature is being lifted. The commutator should preferably be set upon a tapered seat on the shaft, forced up to its seat, and secured with a nut and lock, besides being provided with a key to prevent turning. With such an arrangement, the problem of putting on or taking off a commutator is very much simplified. Great care should be taken to eliminate every possibility of the device becoming loose, as such a defect gives rise to others, among which can be named open-circuited leads and consequent sparking. Great care should be taken to secure the best insulation between the bars and the shell, and from bar to bar, as a breakdown in the commutator insulation has the same effect as a breakdown in the insulation of the armature winding itself. The commutator bars should be perpendicular to a plane at right angles to the shaft, so that the brushes will not, in effect, set on a diagonal and cover more bars than they should. To secure the best results, the brush holders should be set as close to the commutator as possible, so as to do away with chattering. This is most desirable on machines that are to run in both directions, and the brush holder should, on such machines, be designed to slide radially inwards, so that wear in the commutator can always be readily compensated for.

16. If a dynamo or motor is not abused with too much overload, if the brushes are set properly, and if the commutator is made of the proper material, it should seldom get rough. As a rule, sandpaper and emery cloth are used around machines much more than they should be. For ordinary roughness of the commutator, due to some temporary abnormal condition, it is well enough to use sandpaper, but for chronic roughness some more permanent cure must be applied, as there is some serious cause behind the trouble. Take any of the following troubles, for example:

If a commutator, when it is built, is not properly baked or screwed down after it is baked, it is liable to bulge out in the course of time under the action of the heat due to its normal load and the centrifugal force, or it may develop loose bars. In the case of the bulging of one side, sandpaper will not do any good, because from the nature of the way in which it must be applied, the low part gets as much sandpapering as the high part and the relation between the two is kept the same. The best thing to do with a commutator that bulges badly is to take it off, bake it so as to loosen the insulation, tighten it up well, and turn it off in the lathe. For ordinary curvatures of surface, that is, unevenness due to wear, it is customary to set up a tool post and slide rest on the bedplate of the machine itself and turn off the commutator in position.

If the machine is a dynamo, it is run from its engine, which must be run very slowly; if the machine is a motor, its speed must be cut down by putting a water resistance in series with the armature but not with the field; in either case, a tool with a diamond-shape point must be used and the speed must be such that the bars will not be burred nor the nose of the tool burned. Keep the cutting point just about opposite (but a trifle above rather than below) the center of the commutator. After the commutator is turned, it should be smoothed off with a file and sandpaper, any burrs between the bars should be picked out, and vaseline sparingly applied through the pores of a coarse canvas rag. Always have the brushes raised when sandpapering a commutator, even if the machine has to be given a start and allowed to run on its own momentum, because, otherwise, the brushes will catch all the dust, with the result that they are apt to get clogged or the commutator become scratched. Outside of this, it is dangerous to sandpaper a machine that runs with an excited field and at a high speed, because the flying copper dust might be the cause of a short circuit that will burn the operator. This has happened more than once.

A narrow scratch or several of them all around the commutator means that there are particles of hard foreign matter under one or more of the brushes; the best thing to do is to take out the brushes and clean them. A broad scratch around the bearing surface of the commutator probably means that one of the brush holders has been set too close or has become loose and slipped down to a point where it touches the bars. The same scratchy appearance around the ears of the bars probably means that the armature has too much end play or that one of the brush holders is set over too far.

17. High Bars.—A metallic click emitted twice, four times, or six times (according to the number of brush holders in use) per revolution, indicates a high bar in the commutator; in such a case, the brushes will be seen to jump a little when the high bar passes under them. A high bar can come about in either of two ways: it may be due either to a loose bar working out or to the fact that one bar is much harder than any of its neighbors, and, therefore, does not wear down at the same rate. If the high bar seems to be firm under a blow from a hammer, it will be safe to take it down with a file while the armature stands still; but if the hammer test proves the bar to be floating, it is a serious matter, and nothing short of a regular repair job will give satisfaction. In testing a bar or bars with the hammer, care must be taken not to nick or dent the commutator, as such a defacement will cause the high-bar click to be emitted and it will be misleading.

18. Low Bars.—A fault very much akin to a high bar but much more serious in most cases, is the low bar, which gives forth very much the same sound, but the brushes drop, instead of rising, as the fault passes under them. The low-bar trouble may be due to any of several causes: it may be due to the commutator having received a severe blow in the course of handling; to one or more bars being of poorer material than the rest; or it may be due to the gradual eating away of the bar on account of sparking at that particular place. On any but ordinary bipolar machines, a loose connection will generally affect more than one bar. The main difference between a high bar and a low one is in the amount of work required to remedy them. A high bar can be removed by filing down or turning down that bar alone to the level of the others, but to get rid of a low bar, the rest of the commutator must be brought down to its level. This means that unless the low bar or flat is very slight, the commutator must be turned off. There are several other faults pertaining to commutators that will be taken up under the head of "Sparking."

19. Of course the most serious condition is to have a commutator that is poorly made and of poor stock. If the mica and copper used are not of the proper relative hardness, one will wear down faster than the other, leaving the surface of the commutator a succession of ribs. If the mica is too soft, it will pit out between the bars, leaving a trough to fill up with carbon dust and in a degree short-circuit the

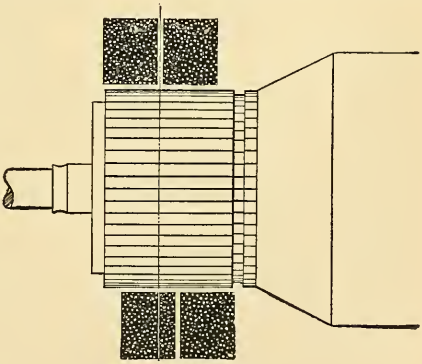


FIG. 8.

neighboring armature coils. If the mica bodies are too hard or too thick, the bars will wear in ruts and call for frequent turning down. The best combination for all-round work is made of soft, clear mica and hard-drawn copper. One practice of the day, and one that tends to materially increase the life of a commutator, is to so design the shape of the commutator bars and the set of the brushes, and to so proportion the end play of the armature that the brushes will play over the whole wearing surface of the commutator.

Fig. 8 shows such a disposal of the brushes, which are said to be **staggered.** The plan is to have the brushes so disposed that no ridges can be formed either on the outside edges or center of the commutator.

THE ARMATURE.

20. Armatures should be handled with great care, as it is an easy matter to bruise a coil or a lead, and this may not be noticed until the machine is started up and the trouble begins. All armatures should be supported by their shafts as much as possible, and should not be rolled around on the floor at the risk of having a coil punctured or a lead broken. When lying on the floor, they should lie upon padding of some sort. Extra armatures not in use should be kept housed in a dry place. The bearings and end play of the armature in use should be closely watched so that the core may not be let down on the pole pieces.

21. Heating of Armatures.—An armature should run without excessive heating; if it heats so as to give off an odor, any of several things may be the matter with it. It may be damp—a condition that, as a rule, is shown by steaming, but which can be better determined by measuring the insulation to the shaft with a voltmeter. This insulation should be at least 500,000 ohms when the machine is hot. If less than this, the armature should be baked, either in an oven or by means of a current passed through it in series with a lamp bank or water resistance. In using a water rheostat watch it closely, for the current increases as the water becomes hot. The baking current should not exceed the full-load current of the machine. In applying the current to the armature, be sure that the series field, if the machine has one, is not included in the circuit, and that the shunt field is broken; for if either field is on, the machine may start up as a motor. A machine that is too damp to run will heat at no load as well as at full load.

22. Another cause of heating under no load is due to the commutator being partially short-circuited all around from bar to bar, so that even when the coils are in the most active part of the field, a strong current can be set up through the local circuit provided by the coils themselves, the commutator bars to which their ends are attached, and the defective insulation between these bars. Such a condition often arises on an old machine, where the oil applied to the commutator has soaked into the mica bodies and carbonized. There is a case on record where the commutator was so short-circuited in this way that the machine would not start as a motor, because the applied current passed through the commutator instead of through the armature coils. The only true remedy for such a trouble is to put on a good commutator. Temporary relief can sometimes be obtained by taking a deep cut off the commutator, thereby removing the most defective part of the insulation.

23. If instead of the whole armature running hot, the heat is confined to one or two coils, the indications are that there is a short circuit either in a coil or between the two commutator bars that the ends of the coil connect. Such a short-circuited coil run in a fully excited field will soon burn itself out. A short circuit of this kind can be readily detected by holding an iron nail or a pocket knife up to the head of the armature while it is running in a field; any existing short circuits in the coils or commutator will cause the piece of metal to vibrate very perceptibly. One or more coil connections reversed on one side of the armature will, on a dynamo, cause a local current to flow from the strong half to the weaker half, and thereby cause all the coils to heat more than they should, besides decreasing the effective E. M. F. of the machine. On a motor, the effect is to decrease its counter E. M. F. so that it will take more current under given conditions, while the side containing the reversed coils will be hotter than the other side. The test for such a condition is to pass a current into the coils, one at a time, through the commutator bars, and to hold a compass needle over the coil that is connected to the two bars being fed; as soon as the reversed coils are reached, the compass needle will reverse the direction of its deflection. The coils must be disconnected and their ends reversed.

24. A broken armature lead or an open-circuited coil soon declares itself by causing a spark to travel around the commutator. A grinding, rumbling noise accompanied by excessive sparking and perhaps some slipping of the belt indicate that the bearings have worn down, letting the armature rub on the pole pieces. This is a trouble that takes place too often, and there is no excuse for it, for even if one does not know how long a set of bearings should run, he can easily tell how much wear has taken place by gauging the distances between the armature core and the top and bottom pole pieces. In such a case, the whole surface of the armature becomes hot and the bottom pole pieces and armature core show signs of abrasion.

25. An armature will sometimes get very warm through no fault of its own, but through heating from an abnormally hot bearing. Heat due to such a cause can generally be detected by the odor given off by the hot oil. Another serious trouble to which armatures are liable, especially motor armatures, is a bent shaft; this causes a very characteristic rattling noise to be emitted, the brushes spark, and the belt sometimes wabbles. The only thing to do with a bent shaft is to take out the armature and straighten its shaft. After straightening the shaft it may be necessary to turn down the commutator before it will run true, as the bend in the shaft may have existed to a slight extent for several months.

26. One very peculiar fault to which armatures are liable is known as a **flying cross.** This is due to a loose wire that only gives trouble when the armature is in motion. The loose wire may either be broken, it may have a loose connection, or it may have defective insulation that allows it to come into contact with other wires as soon as the armature comes up to speed. In any case, the fault gives no trouble as long as the armature is at rest, but as soon as it gets up to speed, the centrifugal force throws the loose wire out of place and causes the brushes to flash. If not located and removed, the fault will, in time, burn a hole in the armature insulation.

27. Overloaded Armatures.—One of the most common causes of general trouble and heating in an armature is overload; this may be due to ignorance or neglect or to an error in the instrument that measures the load. There is a great tendency on the part of owners to gradually increase the load on a machine until it may be doing about twice the work it is intended to do. If the machine is a dynamo, lamps are added to its load one or two at a time; in this way it is an easy matter to overload a dynamo without intending to. If the machine is a motor, small devices may be put on it, one at a time, until an overload is the result. Another very common way of overloading a machine is to increase the voltage at which it is run. Many operators have the idea that as long as the current through the armature does not exceed its proper value, it does not matter what the voltage is, as long as it is not high enough to break down the insulation. The load on a machine is given by the product of the current and the voltage, hence the voltage has a direct influence on the load. If the voltage on a machine is doubled and the current is kept the same, the load on the machine is doubled. Therefore, in order to keep the maximum load the same on a machine whose voltage has been raised, say 25 per cent., the maximum allowable current should be lowered 25 per cent. If the machine is rated at 100 volts and 50 amperes, and it is decided to run it at 125 volts, the current, to give the same load as before, should be 40 amperes. Where machines are running together in multiple, one may be taking more than its share of the load, due to poor equalization. Ammeters sometimes get out of order, read incorrectly, or stick; the needle may stay in one place while the load makes a change of 25 per cent., and the machine tender will be none the wiser.

28. When a dynamo is overloaded the commutator becomes rough, the brushes burn up and spark, the belt squeaks, and the machine grows hot all over. If it is possible to find a non-sparking point for the brushes at some intermediate load and at no load, this should also be possible at full load. If it is not possible, the symptoms point to overload and the ammeter should be tested. Of course, some machines spark badly no matter whether they are overloaded or not. This is specially true of the older types. When a machine persists in sparking when the commutator and everything else about it is in good condition, the trouble may generally be attributed to poor design. Some machines are so poorly designed that it is practically impossible to keep them from sparking.

FIELD COILS.

29. We generally have two kinds of **field coils** to deal with, namely, *shunt* and *series*, or both, depending on the style of machine. These may be further subdivided into two classes, form-wound and shell-wound. Fine-wire fields are usually called **shunt fields** because they form a shunt or bypath for the armature current on a dynamo or the line current on a motor; they are of high resistance, so that they will take but a small part of the current supplied to or by a machine, and they are subjected to the full line voltage, as indicated in Fig. 9 (*a*), where *A* is the armature and *f* is the shunt field. Coarse-wire fields are usually called **series fields,** because they are in series with the armature, and should be able to carry the current that flows through the armature. They are of low resistance so that they may consume as little as possible of the voltage supplied to or by the machine, and as a result are subjected to but a small E. M. F., as indicated in Fig. 9 (*b*), where the drop through the series coils is supposed to be 2 volts. No matter what kind of field may have to be handled, the coils, leads, and connecting lugs should be handled with great care. The bearing surfaces of the coil should be brushed off before the coil is put in place, to avoid having any chips of foreign matter mashed into the insulation when the field bolts are screwed home.

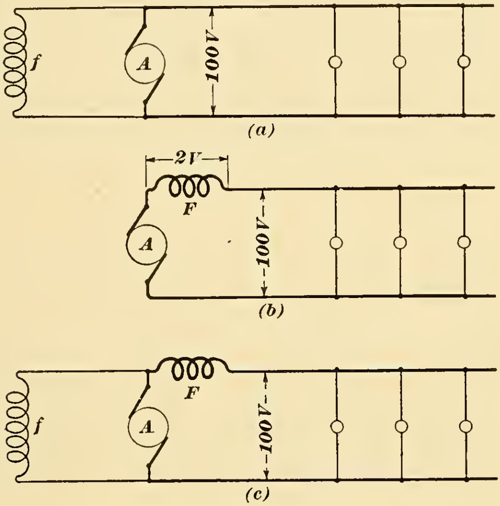


FIG. 9.

30. Field coils should be installed in such a way that when the current passes through them, if one pole piece is called north, the poles on both sides of it will be south. Coils, as a rule, are marked so that the workman may know exactly where they are to go and which end is to point toward the commutator. It is usually easy to tell by the shape of the field which face of it is to go next to the frame of the machine and which next to the armature. If the coils are not marked or if there is any doubt about the marks, the matter can be settled as follows: Set the field coils on the floor and line them up on edge, as shown in Fig. 10; connect them together and send a current through them. Get them, by trial, so that a piece of soft iron, held in the hand, will pass in an easy curve, as shown at *I*, from one coil to the other, the same end on. Should the piece of iron try to take the position shown at *I′* between any two coils, reverse one of them. When the coils are all turned so that the iron takes the curved path from one to the other, put them in place on the machine in this same relation, for then it is certain that they will alternate in polarity. A more certain test, perhaps, is to put the field coils into the machine as it is thought they should go (leaving out the armature), and test them with a compass or piece of soft iron the same as before. In using a compass, care must be taken that it does not stick, for then the lines of force of the field are liable to thread through it backwards and reverse its polarity; if this takes place just at the wrong time, it may be misleading. The reason for making the test without the armature in place is that the pole induced in the armature core opposite each pole piece is apt to influence the action of the compass.

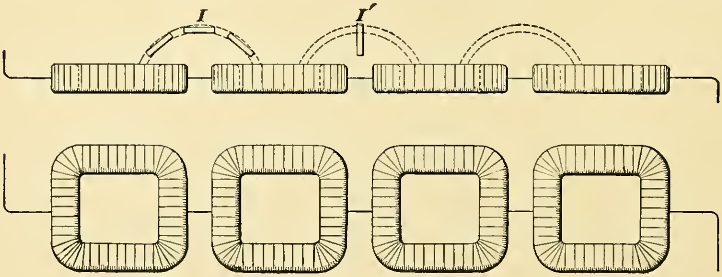


FIG. 10.

31. The effect of putting a field coil in end for end on a dynamo is to decrease the voltage that it will generate even on open circuit, and perhaps render the machine unable to generate at all. On a motor, the effect is to greatly increase the current required to start, to abnormally increase the speed after it is started, and to cause the brushes to spark. If a motor has only two fields and one of them is connected incorrectly, the machine will either not start at all or else it will start very slowly and take a very large current. A two-field dynamo cannot generate, under the same conditions even if excited from some other source, unless one coil happens to be a little stronger than the other, in which case the machine might generate a small E. M. F.

32. Where the machine is compound-wound, the two windings generally occupy parts of the same spool. Great care should be taken to get both sections properly connected. On a dynamo, if the shunt field as a whole is connected correctly but the series field incorrectly, the machine will pick up its field and hold it, but it cannot be made to take a full load; for as soon as the main switch is closed and current goes through the reversed series coils, their magnetizing force partially neutralizes that of the shunt coil, reducing the E. M. F. of the dynamo and fixing a limit above which the load cannot be made go. If the shunt fields are wrongly connected and the series field are correctly connected, the machine will not pick up its field at all on open circuit, and whether it will or not on closed circuit depends on the resistance of that circuit. This resistance must be very low for the comparatively few turns of series field to pick up through it, and even if it did, the resulting voltage applied to the terminals of the wrongly connected shunt field would bring about a neutralization of magnetism, and the E. M. F. would fall again.

33. On a motor it does not matter so much whether or not the shunt and series fields, as a whole, are connected to assist or oppose each other, unless the machine has been heavily over-compounded to run as a generator, in which case, if it is desired to use the series coils for maintaining constant speed under a variable load, it will be necessary to put a shunt in multiple with them. When a compound-wound motor is so connected that its series and shunt coils assist each other, it is said to be *accumulatively* connected, and it then has its greatest starting power for a given current. When the two fields oppose each other, the motor is said to be *differentially* connected, and if the strength of the two windings is in the proper relation, the speed of the motor will be constant within reasonable variations of load, if the voltage is constant. If, however, the series coils are too strong, the machine will run faster at full load than at no load, taking a great deal more current than it would with the reverse connection of the fields and perhaps sparking at the brushes.

34. Every dynamo, whether series, shunt, or compound-wound, must have its fields connected in a certain way, in relation to the armature and the direction of rotation, or it will not generate. The direction of rotation of a motor depends on the connection of its fields and armature, and it can be reversed by reversing either of these, but not both. When a motor runs in a certain direction, a certain relation exists between the directions of the currents in its armature and field; when either of these currents is reversed, it changes this relation and with it the direction of rotation; but when both are reversed, which corresponds simply to changing the polarity of the dynamo that runs the motor, the relation remains the same and so does the direction of rotation. Exchanging the places of the terminals applied to a motor (unless it is separately excited) will not change its direction of rotation. For given armature and field connections, a shunt machine will run in the same direction as a motor that it does as a dynamo; a series machine will run in the opposite direction in the two cases, while the direction in which a compound-wound machine will run as a motor depends on the relative strength of the two windings and on the conditions under which the motor is started.

FIELD-COIL TROUBLES.

35. Fields, like armatures, are subject to troubles of various kinds; they are liable to open circuits, short circuits, and grounds. An open circuit can give rise to various effects, depending on the conditions under which the machine operates and also on the style of machine. In the case of a series dynamo, an open circuit in the field will render it totally incapable of operating either as a motor or a dynamo, but no harm can come to the machine itself, unless the fault should take place while the current was on, in which case it would be apt to burn a hole in whatever happened to be around the break.

36. On a shunt machine, the amount of trouble caused by the opening of a field coil depends on whether the machine is a motor or a dynamo; and if a dynamo, on whether it runs alone or in multiple with other dynamos. If the machine is an isolated dynamo, a break in the field coil can do no further damage than to prevent the machine from generating and, hence, cut off the current from whatever lamps or motors may be operated by it. If, however, the dynamo is in multiple with other dynamos on the same load, the result of such a fault will be that the other machines will send a large rush of current back through the faulty machine and cause, practically, a short circuit.

37. Series dynamos are not, as a rule, run in multiple. If a shunt dynamo that is ordinarily run as a dynamo is made to run as a motor by current being backed through it, it will keep on running in the same direction, but will spark at the brushes, owing to the fact that the brushes are in a place suited to dynamo running and not to motor running. If the dynamo is compound-wound, the direction that it will try to run when it becomes a motor depends on the position of its brushes and mainly on the relative strength of the series windings and shunt windings. Breaking the field of a dynamo in multiple with other dynamos amounts to the same thing practically as breaking the field on a shunt motor.

Breaking the field of a shunt motor destroys its counter E. M. F., so that there is no opposition to the line E. M. F. and there is practically a short circuit through the armature. As the field magnetism dies down slowly, the counter E. M. F. dies down also, and the short circuit does not take place so quickly but that the faulty machine may acquire a very high rate of speed and throw its belt or do other damage before the fuse or circuit-breaker acts.

38. An open circuit in the field of a shunt motor in action, then, results in a short circuit, abnormal speed, throwing off the belt, and opening the circuit-breaker. On a compound-wound motor connected accumulatively, the speed will not reach such a high value, because the series coils hold it down; but if the motor is differentially connected, as soon as the shunt field breaks, the series coils opposed to it bring the motor to a stop and start it up in the opposite direction. If the fault should occur while the motor is standing still, it would be impossible to start a simple shunt motor with a safe current. A compound-wound motor will, if the starting current is large enough, start up on the field provided by the series-turns; but it will start up in the wrong direction if the series coils are so connected as to oppose the shunt coils.

39. The effect of the reversal of a single field coil on a machine depends on how many field coils the machine has, in other words, the more poles a machine has, the less will be the effect of an irregularity in one of them. If the machine has only two coils and one of them is incorrectly connected, the machine will not start as a motor and it will not generate as a dynamo. If there are four field coils, it will take a heavy current to start it as a motor, and the brushes will spark even while the motor is starting. As a dynamo, most machines will refuse to pick up their fields at all, except at very high speeds, and even if separately excited, the voltage at normal speed will be below its proper value. On machines of more than four field coils, the same symptoms hold good, but to a less degree, and are characterized by sparking at the brushes that include the faulty field.

40. One other fault producing effects very much like the above is loose joints in the magnetic circuit. Where a machine has two halves fitting together, great care should be taken that no particles of foreign matter are allowed to get in the joint and so introduce an air gap into the magnetic circuit. The same precaution holds good in regard to machines having detachable pole pieces. The effect of a loose, or open, joint in the magnetic circuit, as in the case of a reversed field coil, is to weaken the field of the machine, so that on a dynamo there will be trouble picking up the field at normal speed, and the open-circuit voltage will be reduced by an amount dependent on the seriousness of the fault; while on a motor the starting current will be greater and the speed higher than it should be.

The effects are aggravated where the dynamo or motor is running in multiple with others. If a dynamo, it will be unable to meet the requirements of the rush hours, because its voltage cannot be increased enough to make it claim its share of the total load; it will require close hand regulation under varying loads, because its voltage will not vary at the same rate as that of its neighbors, although it may be the same kind of a machine. The best illustration of the condition applied to motors in multiple is found on an electrically propelled car where the two or more motors are practically rigidly connected within certain limits of load. The motors when doing their heaviest duty are in multiple, and the one whose path offers the least resistance takes the most current. The motor that has a reversed field coil or a loose, or open, joint in its steel frame, has a lower counter E. M. F., and hence has less apparent resistance; it will then be only a matter of time when this motor will cause the car to repeatedly blow its main fuse. The motor will become hotter than its mate, the brushes will spark, the commutator will blacken and become rough, the armature throw solder, and a final inspection will probably show that all the cotton insulation on the field wire is baked or charred.

41. Short Circuits in Field.—The action of a short circuit in a field coil depends on the kind of machine, the manner in which the field coils are connected, and whether the short circuit is a good or bad contact. Take a shunt dynamo, with four field coils; if the coils are in series, as in Fig. 11 (*a*), so that the voltage across each coil is only one-fourth of the total voltage, a good short circuit in a single coil will cause it to run comparatively cool, while the remaining coils will get unusually warm. A bad contact is apt to emit more or less of an odor of burning shellac and other insulation. The cutting out of a single coil in four will reduce the resistance of the field circuit so that more current may flow through the remaining coils in an attempt to make up the loss of magnetism due to the cutting out of one coil, but this automatic compensation will not be so much but that the field rheostat resistance will have to be lessened to keep up the dynamo voltage.

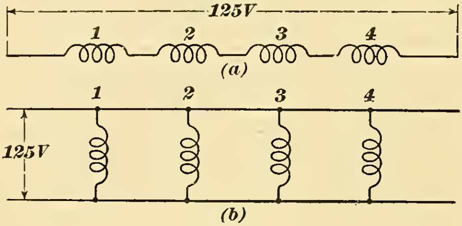


FIG. 11.

42. On the other hand, if the shunt coils are all in multiple, as shown in Fig. 11 (*b*), the faulty coil will be the one to get hot and the rest of the coils will run at normal temperature. If the fault is such as to cut out the coil entirely, the machine will loose its field, because a shunt machine will not support a field on short circuit. On a compound-wound dynamo running alone, a short circuit in the shunt winding will cause about the same symptoms, as far as the heating goes, as in a shunt machine. If the shunt coils are in multiple and connected as shown in Fig. 12 (*a*) (*short shunt* connection), the dynamo will drop its field if one shunt coil is dead short-circuited; but if the shunt coils, as a whole, are connected as shown in Fig. 12 (*b*) (*long shunt* connection), so that the series coils are in series with the

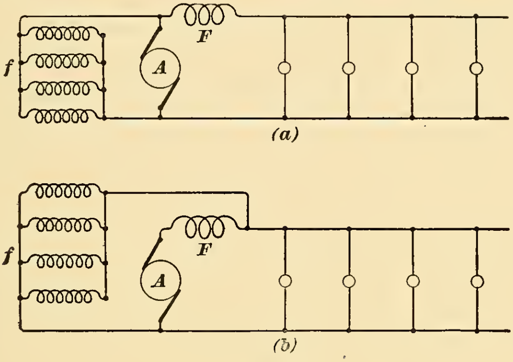


FIG. 12.

fault, the dynamo will throw its belt because the series coils work under the best possible conditions—a short circuit.

43. Moisture in Field Coils.—Moisture in field coils will cause them to heat and make the brushes spark. Before putting such fields into actual service, they should be baked out, either with the current or in an oven. Moist field coils, as a rule, steam when hot, feel moist to the hand, and their insulation to the frame of the machine measures low. The most refined way of locating a short-circuited field is to measure the resistance of the field suspected and compare it with that of a standard field of the same kind. A variation of over 10 per cent. should not be allowed, and where the fields are in multiple, not over 2 per cent. variation should be allowed. A short-circuited shunt field can be located by short-circuiting or cutting out one field coil at a time and measuring the open-circuit voltage of the dynamo.

44. Grounded Field Coils.—A grounded field is a very common source of trouble in some classes of work, but a very unusual one in others. Commercial circuits may be divided into two classes, namely, *metallic-return* and *ground-return circuits*. On metallic-return circuits, both the outgoing and return wires are insulated from the earth. Ordinary lighting and conduit trolley systems are examples of metallic-return circuits. Ordinary street-railway systems are examples of a grounded circuit, since the trolley wire constitutes one side and the ground or track the other. The indications of a grounded field depend on whether the machine is on a metallic-return or a ground-return system, and if on the latter, whether the machine is a dynamo or motor and what place the field occupies in the circuit.

Metallic-return systems are, as a rule, characterized by having very little trouble from grounds; because, in the first place, since neither side of the system is permanently grounded, there is but half the tendency for either side to ground; and in the second place, a single ground does not at all disturb the operation of the devices, because another ground is necessary to complete the circuit. Should two grounds develop, one on each side of the circuit, or at two places in a device, a short circuit follows; but, as a rule, a single ground can be detected and removed before another occurs to cause trouble. Lightning is responsible for many of the grounds on metallic-return circuits. Inasmuch as ground troubles are more common on ground-return circuits, we will devote our limited space to this class of work.

45. Fig. 13 shows a shunt dynamo at work on a grounded circuit, the ground return being indicated by the dotted line. Suppose a ground takes place at *a*; the result will

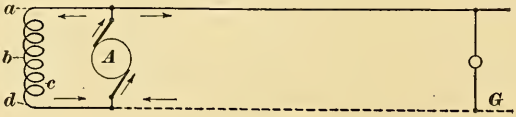


FIG. 13.

be a dead short circuit across the line, under which condition the dynamo will drop its field. A ground at *d* will have no effect, as that side of the circuit is already grounded. A ground anywhere between *a* and *d* will cut out a part of the field and severely heat the part not cut out.

46. Fig. 14 shows a compound-wound dynamo with the shunt field connected inside of the series field. A ground at *a* will cause the dynamo to drop its field as before; a ground at *d* will not be felt. A ground at *b* will cut out a part of the field and the remaining part will heat badly; the voltage on the line will drop. Fig. 15 shows a compound-wound dynamo with the shunt connected across the terminals of the machine instead of across the brushes. This alters the conditions very much. A ground at *a* establishes a short circuit through the series field. The shunt field is cut out entirely and the line loses its power, but, owing to the strong current in the local circuit *A–F–a–d–A*, the dynamo throws its belt unless the circuit-breaker acts quickly. A ground at *b* will give the same indication as in the case of Fig. 14.

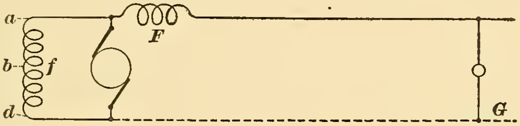


FIG. 14.

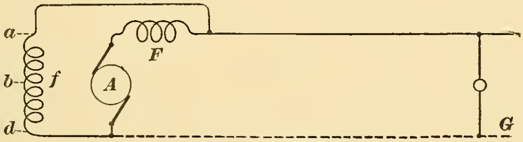


FIG. 15.

47. Fig. 16 shows a series dynamo at work on a grounded circuit. A ground anywhere on the field will cut the power off the line. A ground anywhere near *a*, unless the dynamo is of the arc-light type with very heavy armature reaction, will throw the belt. A ground anywhere near *b* will simply cut out the field and the machine will stop generating.

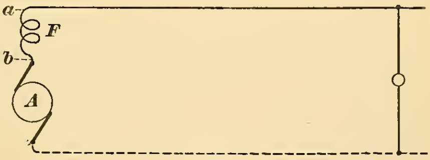


FIG. 16.

Fig. 17 shows a series machine as in Fig. 16, but with the field next to the ground. A ground at *a* will cause the dynamo to stop generating; a ground at *b* might cause it to drop its voltage and it might not, depending on the amount of resistance in the load; if this resistance is small, the dynamo will generate a lower voltage. A ground at *d* will not be felt.

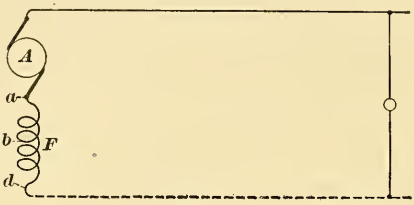


FIG. 17.

48. Let us suppose now that the dynamo in each of the above figures becomes a motor; the current, instead of coming from within the machine, comes to it from an outside source. In Fig. 13, then, a ground at *a* when the machine is running will cut out the motor so that it can get no power, the circuit-breaker will fly out or the motor will throw its belt, owing to the fact that in virtue of its momentum it will become a dynamo running on short circuit, both ends being grounded, one permanently and the other through the fault. The effects for the other grounds will be about the same as in the case of the dynamo.

In Fig. 14, a ground at *a* will cut out the shunt field and stop the motor very suddenly, as the armature will be grounded at both ends, and the series coils will be heavily charged by the current passing through the fault. The machine will really become a separately excited dynamo on short circuit. A ground at *b* will cause part of the field to heat badly, and a ground at *d* will have no effect.

In Fig. 15, a ground at *a* will cause practically the same action as in Fig. 14 and for about the same reason. In both cases, the motor will probably throw its belt. A ground at *b* and *d* will cause the same action as in the case of the dynamo.

In Fig. 16, a ground almost anywhere on the field, except at *a*, will separately excite a part of the field and bring the armature to a sudden stop, owing to its dynamo action through the short circuit. A ground at *a* can cause no action of this kind, because the dynamo has no shunt field; and although the armature is permanently grounded on one end and is grounded through the whole series field on the other end, it cannot generate, because a series machine runs in opposite directions as dynamo and motor, for given connections; so that the direction in this case is not the right one. The motor of Fig. 16 finds its practical parallel in the street-railway motor as it is today. Fig. 17 is the same thing, only the fields are next to the ground, so that a ground in a field coil does not cut out the armature.

In Fig. 17, a ground at *a* cuts out the field and the entire short-circuit current passes through the armature, causing violent sparking that burns the brushes and commutator. A ground at *b* cuts out all the field below it, weakening the field and causing the armature to take an excessive amount of current. A ground at *d*, as in former cases, has no effect at all. Placing the field next to the ground has the disadvantage that a ground may take place in such a part of the field that the armature may be overloaded a long time before the fact is known; but it has the advantage that, being on the negative side of the armature, the difference of potential between the positive side of the field and the ground is very small, so that there is not as great a tendency for grounds to develop as in the first case. It is a well-known fact that cars equipped with motors whose fields are next to the ground give much less trouble from grounded fields than cars whose fields are next to the trolley.

REASONS FOR A DYNAMO FAILING TO GENERATE.

49. Loss of Residual Magnetism.—Among the many causes which may make a dynamo fail to generate, loss of residual magnetism is often one of the most troublesome. The magnetism that remains in the steel or iron frame after the field current is cut off is called **residual magnetism,** and every dynamo must have a certain amount of this to start on before it can build up its field. As a rule, dynamos leaving the factory retain enough residual magnetism to start on, but there are several ways in which they can lose it; they sometimes lose it after having given no previous trouble of that sort in months or years. Some dynamos never lose their residual magnetism, or **charge,** as it is called, while others seem to have a weakness for doing it.

In many cases the peculiar action cannot be explained; in some cases it may be due to any of the following conditions: (*a*) Excessive vibration; hence, the dynamo should always rest on a solid foundation. (*b*) To the earth's magnetism; where practicable it may be well to set the machine so that its north pole is toward the north; then the earth's magnetism will pass through the machine in the same direction as its own. The earth's magnetism is very weak, but when assisted by vibration it may sometimes be sufficient to counteract the residual magnetism. Only two-pole machines can be really set to fill this condition, as on multipolar machines the poles radiate in all directions. (*c*) A dynamo set very near another dynamo; in such a case, stray lines of force from a loaded dynamo may thread their way through the magnetic circuit of an idle one in the reverse direction and neutralize its residual magnetism. (*d*) The fields accidentally given a slight flow of current in the wrong direction; this can very easily occur on a compound-wound or series dynamo, as current from the outside will always pass through the series coils in the opposite direction to that in which the current from the machine itself would pass. In shunt machines, however, this is not so, for as a motor, the field winding shunts both the armature and the line. (*e*) The machine started up with the fields or armature as a whole incorrectly connected, that is, reversed; in this case the result will be to destroy whatever residual magnetism there may have been. (*f*) The field circuit broken too suddenly; when a field circuit is suddenly broken, the residual magnetism is sometimes brought down to zero or even reversed.

50. Where a dynamo has lost its charge, the pole pieces will have little or no attraction for a piece of soft iron. There are several ways in which the charge may be restored. Series dynamos seldom lose their charge so entirely that they will fail to pick up a field on short circuit. Where a compound-wound dynamo refuses to pick up a field with its shunt field, it can often be made to pick up by disconnecting the shunt coils and short-circuiting the machine through a small fuse that will prevent damage due to the short circuit. The same idea in a modified form may be used on a plain shunt dynamo by temporarily connecting all the shunt coils in multiple instead of series. This makes the machine a series dynamo with a low-resistance circuit. Any machine can in many cases be made to pick up a field by simply short-circuiting the armature by holding a piece of copper wire across the brushes or by rocking the brushes back from their neutral position. The effect is to make the magnetism of the armature help the field to build up.

If none of these expedients produce the desired result, the fields must be recharged from an outside source. If the dynamo runs in multiple with other dynamos, this is an easy matter; it is only necessary to lift the brushes or disconnect one of the brush-holder cables on the dead machine and throw in the main-line switch, the same as if the machine were going into service with the others. The fields will then take a charge from the line and their polarity will be correct. After the field has been charged, the brushes or cable must not be moved until the main-line switch is open, because a short circuit will be made. If the dynamo does not run in multiple with another and there is a dynamo within wiring distance, disconnect the shunt field of the dead dynamo and connect it to the live circuit. The live circuit may be the trolley wire of a street-railway circuit. Bear in mind, however, that this is a 500-volt circuit, so that if it is to be used for charging 125-volt fields it must be applied for only a couple of seconds. There have been cases where it has been necessary to run a couple of wires a quarter of a mile, or more, to obtain current for charging a field. If there are absolutely no other means available for charging, several cells of ordinary battery must be used; connect the field coils in series with the cells in series and give the pole pieces of the dynamo repeated knocks with a hammer while the charging is going on; if this fails, reverse the terminals of the battery and repeat the operation—it may be that the first time the battery is applied its magnetizing force opposes what little residue magnetism there may be in the iron. As a last resource, when all other available sources fail, connect the fields so as to obtain the least possible resistance, put them in series with the armature through a small fuse, and speed the armature considerably above the normal rate. Very often a dynamo, instead of losing its residual magnetism, will acquire one of a reversed polarity, due, perhaps, to the same causes exercised to a greater degree. Except where the dynamo is used for charging storage cells, or for electroplating, or for running arc lamps, or for running in parallel with other machines, the reversal of its polarity can do no harm. In case an arc machine is reversed, the concave carbon will be the bottom one and most of the light will be thrown up instead of down, where it is generally desired.

51. Wrong Connection of Field or Armature.—Every dynamo requires that a certain relation exist between the connection of its field and armature and its direction of rotation, or it will refuse to generate. Suppose a dynamo to be generating; if its field or armature connection (either, but not both) be reversed, it will be unable to generate; or if all the connections be left intact and the direction of rotation reversed, the machine will be rendered inert. Not only is it unable to generate with the wrong connections or rotation, but a short run under this condition will render the machine unable to generate after the conditions are corrected, unless the field is recharged. because the effect is to destroy its residual magnetism.

Let us see why such is the case. It sometimes happens that when a dynamo is first started it has a small E. M. F. due to the residual field; but upon closing the field circuit, the E. M. F. falls to zero and the machine refuses to generate. Such action indicates a wrong connection of field or armature for the given direction of rotation and can be explained as follows: Suppose the dynamo to be properly connected and to be generating; this implies that the field current is in such a direction as to produce a magnetic field that reinforces the residual field. Now, without disturbing anything else, let the field terminals be reversed; for the sake of clearness, we will suppose that there remains a residual field due to the current last flowing. Under this condition, the lines of force due to the residual field are in the same direction as they were when the machine was properly connected and generating; the small current now generated in the armature, and due to the residual field, will be in the same direction as it was then, but the field connections being reversed, the current flows around the poles in such a direction as to neutralize their residual magnetism. The weak residual field is now opposed by this new field and soon the residual field is reduced to zero, thus totally depriving the machine of all ability to pick up. Nor can a reverse field, even if established by recharging, be maintained; for, assuming a reversed residual magnetism to be provided, the lines of force have changed direction, the armature current does likewise, and previous conditions being reestablished, the residual field is again destroyed. If, then, a dynamo fails to generate, and all other conditions are apparently correct, reverse the field leads and again try to make the dynamo generate. If a loss of residual magnetism is indicated by very weak poles, recharge the fields.

52. Open Circuits.—A series dynamo cannot, of course, pick up its field if any part of the circuit is open, for there is but one circuit. It cannot pick up its field if the resistance of its outside load is above a certain value peculiar to each machine, for as a rule series dynamos supply devices that are also in series, and every device added means more resistance for the machine to pick up through. As it will not pick up through a high resistance, it is customary to provide series dynamos with a switch, by means of which the line and machine are short-circuited at starting, so that the load is not thrown on until the dynamo picks up, after which the short-circuiting switch is opened, leaving the line properly connected to its terminals. A shunt, or compound-wound, dynamo will not pick up if the shunt field circuit is open; the open circuit may be in the field itself, in the field rheostat, or in some of the wires or connections involved in the circuit. A careful inspection will generally disclose any fault that may exist in a wire or connection; to find out if the rheostat is at fault, short-circuit it with a piece of copper wire; if the dynamo generates with the rheostat cut out, the fault is in the rheostat. To find out if the open circuit is in a field coil, use a test-lamp circuit or a magneto-bell to test the coils one at a time. Before doing so, be certain that all communication is cut off between the machine under test and the line, if there are other machines on the same circuit. In making this test, bear in mind that if the dynamo is compound-wound and connected as shown in Fig. 15, an open circuit in the series coils will cut off the current from the shunt coils also.

Connecting wires, in course of time, are liable to be shaken loose or broken by vibration; they should be made of flexible cable, and the screws that hold them may be secured against turning by means of a drop of solder. A field circuit is sometimes held open by a defective field switch that, to all appearances, is all right; repeated burning will oxidize the tip of the blade and make a blister on it; the blister will not carry current and it will press the jaws of the switch apart so that only the blister touches, and so opens the circuit. Another trivial but common cause of open circuits is the blowing of fuses. Fuses of the enclosed type give more trouble in locating the fault than any other kind, because it cannot be told by looking at them whether the fuse is intact or not.

An open circuit in the armature will interfere with the proper generation of the current, but such a fault, as a rule, announces its own occurrence in a very emphatic manner and does not, therefore, require to be looked for. A very uncommon source of open circuit, where copper brushes are used, is due to the burning of the brush heels into oxide. The dynamo will refuse to pick up until the brushes are trimmed and cleaned. When an armature just from the factory refuses to generate where the one just taken out has been generating, the trouble is probably due to either of two causes: There may be shellac on the commutator—in this case, a little coarse sandpaper will set things right; the armature may be a right-hand armature while the one taken out was wound left-hand, or *vice versa.* The expressions right-hand and left-hand here apply to features of winding or connecting, and should such a condition arise, it can be remedied by reversing the armature or field connections, or the direction of rotation.

Before attributing the failure of a dynamo to generate to any of the above open-circuit causes, see that the brushes are on the commutator, the field switch closed, and the greater part of the field rheostat cut out.

Always bear in mind that the E. M. F. generated when a machine is started up is very small because the residual magnetism is weak. It may not require a complete open circuit in the field to prevent the machine picking up. A bad contact that might not interfere with the working of the machine when it is up to full voltage might be sufficient to prevent its picking up when started. A loose shunt wire in a binding post or a dirty commutator will introduce sufficient resistance to prevent the machine from operating. Trouble is very often experienced in making machines with carbon brushes pick up, especially if the brushes or commutator are at all greasy. If such is the case, thoroughly clean off the commutator, wipe off the ends of the brushes with benzine, and see that they make a good contact with the commutator surface. Metal brushes, if kept in good order, do not give as much trouble as carbon in this respect, because their contact resistance is lower.

53. Short Circuits.—A short circuit on the line will make a shunt dynamo drop its field, but the dynamo may throw its belt before it does so. With a short circuit on the line, a shunt dynamo will not, therefore, pick up its field. Such a short circuit may be due to some fault in the pilot-lamp circuit, or it may be due to a motor switch being left in across the line by one of the outside consumers. On this account, it is to the interest of any company supplying power for motors to see that every motor is provided with an automatic cut-out, so that when the line voltage goes below a certain value the motor circuit will open. With a series or compound-wound dynamo, a short circuit on the line increases its ability to generate, because the fault is in series with the series coils and its large current passes through them. A series dynamo, like a shunt dynamo, will not pick up if the field is short-circuited. A compound-wound dynamo will not pick up on open circuit if the shunt field is short-circuited; it will pick up with an open circuit in the main circuit, but will not hold its voltage under load if the series coils are short-circuited. In some cases a shunt dynamo will not pick up on full load, as this realizes too nearly the condition of a short circuit; so that to be on the safe side, it is best to let the machine build up its field before closing the line switch.

Short circuits within the dynamo itself generally give rise to indications that point out the location and nature of the fault. In any event, the first thing to find out is whether the fault is in the dynamo or out on the line; if it will pick up its field when the line switch is opened, but fails to do so with it closed, the trouble is outside of the dynamo. It may be on the switchboard, where a workman may have left a tool or piece of wire lying across the bus-bars. The most common method used to get rid of a cross on the line is to burn it out; this is done by centralizing the entire dynamo capacity of the station, if necessary, on the faulty circuit.

54. Brushes and Brush Holders.—In order for any direct-current dynamo to generate, its brushes must be in a certain position that depends on the type and design of the machine. As a rule, the design of the brush holder gives a clue as to where the brushes should sit, but one cannot say to a certainty where the brushes on a given dynamo should go unless he is familiar with that particular machine, because the position of the brushes is governed by conditions of winding and connecting not apparent to the eye. If the connections were brought straight out from the armature to the commutator bars, the brushes would always sit in line with the center of the space between the polar horns, because this is the position of the neutral field. But very often, for reasons of accessibility, the wires coming from the coils are given a **lead** that brings the normal position of the brushes in line with the centers of the pole pieces. The brushes on a motor sit the same as those on a dynamo, except that on a motor they are given a little lead backwards (in the opposite direction to that in which the armature rotates), while on a dynamo they are given a little lead forwards.

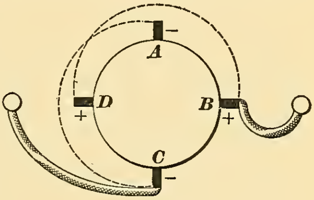


FIG. 18.

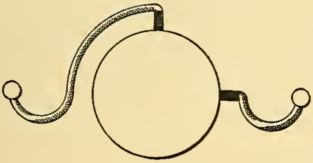


FIG. 19.

Fig. 18 refers to a four-pole machine with four brushes. The proper position for the brushes in this particular case is that shown in the diagram. *A* is on top, *B* to the right, *C* on the bottom, *D* to the left. If the rocker-arm be given a quarter turn to the right or left, so that, say, *A* takes the place of *B*, *B* the place of *C*, *C* the place of *D*, and *D* the place of *A*, it amounts to the same thing as reversing the armature cables or terminals, and the dynamo will refuse to generate.

Fig. 19 also refers to a four-pole armature, but it is so connected that only two sets of brushes are needed, and these two brushes are shown in the position where it is most natural to expect to find them. Fig. 20, however, shows where, for reasons of accessibility, symmetry, and safety, the brush holders are generally found in practice.

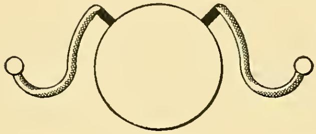


FIG. 20.

55. Field Coils Opposed.—Failure to generate may be due to one or more field coils being incorrectly put on, or connected, so that they oppose each other. The only thing to do is to locate the faulty coil and reverse its connection. On a compound-wound dynamo, the reversal of a shunt-field coil will generally keep the dynamo from picking up on open circuit, unless the dynamo has more than four coils; the more coils it has, the less effect has the reversal of a single coil. The reversal of a series coil is not felt until an attempt is made to load the machine; the voltage will not come up to where it should for a given load and the brushes are apt to spark on account of the weakening of the field.

56. Low Speed.—No dynamo will pick up its field below a certain speed, but with the field once established, the machine will hold it at a much lower speed than that required to establish it. The speed at which a series dynamo will pick up depends on the resistance of the external circuit.

57. Among the causes of failure to generate not included in the above are faults in the iron circuit, loose or open joints in the frame proper or between the pole pieces and the frame. Such imperfections also lower the maximum voltage of the dynamo. An armature core undersize or pole pieces bored out too large will cause the same trouble. There is one peculiar case on record where an extra armature was shipped from the factory and when put in the dynamo refused to generate. The trouble was located in the armature core, which was found to be $\frac{5}{32}$ inch too small in diameter and an inch too short. The armature was given a running test before it left the factory, but it was run as a motor, and as no speed reading was taken, the mistake was not noticed. Occasionally orders become confused in the shipping department and the armature goes out with the wrong pulley; if the pulley is too large, the difference in speed will affect the picking up of the dynamo. Finally, it is possible to send out a 125-volt armature with 250-volt fields, or a 250-volt armature with 500-volt fields; in such a case it is only necessary to connect the fields in multiple to make the dynamo generate, if it should so happen that the voltage of the armature is the voltage wanted.

MOTOR FAILS TO START.

58. When a motor fails to start when the controlling switch is closed, any one of several things may be the matter. There may be an open circuit, a short circuit, a wrong connection, the power may be off the line, or the trouble may be purely mechanical. If the failure to start is due to an open circuit or to absence of power on the line, there will be no flash when the switch is closed and opened again. To tell if there is any power on the line, test with incandescent lamps or a voltmeter. If the fault is an open circuit, it may be found in any of the following places: Defective switch; broken wire or connection in the starting box; loose or open connection in some of the wiring; shellac on the commutator; a piece of foreign matter under one brush; brush stuck in the holder or no brush in it at all; brush springs up; fuse blown; some wire, apparently all right, broken inside of the insulation; or an open circuit in some part of the motor itself. Any of these sources of open circuit may be located with a magneto-bell or with a lamp or bell circuit. If the trouble is due to a short circuit, there will be a flash when the starting box is thrown off.

59. Among the more common sources of short circuit, are these: Short-circuited armature coils; short-circuited commutator; short-circuited field coils; field on a shunt or compound-wound motor connected so that the armature cuts out the field winding; carbonized brush yoke; brushes in the wrong position. If the armature coils or commutator are short-circuited, the machine may start and turn over part way and stop again. With a field coil short-circuited, the armature will start only under a heavy current, with accompanying sparking, and will acquire a high rate of speed.

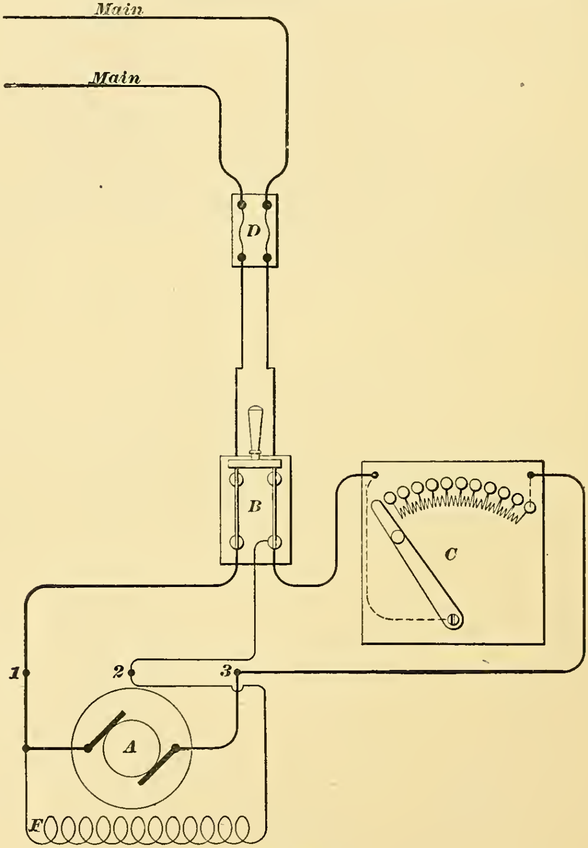


FIG. 21.

60. Fig. 21 shows the correct method of connecting a shunt motor with an ordinary starting box. Shunt motors are usually equipped with three terminals, *1*, *2*, *3*. Terminal *1* takes one armature lead and one end of the shunt field; terminal *2* the other end of the shunt; and terminal *3* the other end of the armature. By examining the figure it will be seen that *2* is connected ahead of the rheostat, so that as soon as the main switch *B* is thrown in, the shunt field is excited from the mains. Then when the handle of *C* is moved from the off position to the first point, the current that flows through the armature has a strong field to react on and the motor starts up with a good torque. Fig. 22 shows the motor wrongly connected. In this case, the wire running from post *2* is connected between the rheostat and the motor instead of being connected between the main switch and the rheostat; in fact, it is equivalent to connecting posts *1* and *2* together. The result is that the shunt field is connected to the armature terminals and no current will flow through it until the starting-box lever is moved over. As soon as the starting-box lever is moved, current flows through the armature, but very little flows through the field because the pressure across the field terminals is only equal to the drop in the armature. The result is that the field is very weak and the motor refuses to start until the starting lever is moved so far over that a very large current flows through the armature. The box becomes excessively hot, and if the fuses or circuit-breaker do not give way, there is danger of something being burned out.

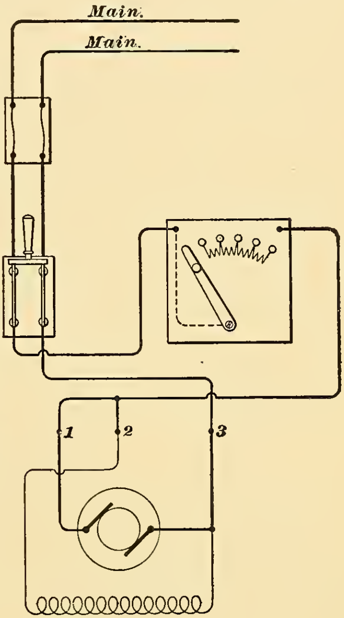


FIG. 22.

61. Wrong Motor Connections.—Wrong connections may be classed under two heads, *internal* and *external.* External wrong connections involve confusion of wires running to and from the motor, and are most likely to occur where a reverse switch must be used to change the direction of rotation of the armature. Such errors as getting an armature wire in where a field wire should go, or *vice versa*, come under this head. Where field and armature leads are of the same kind and are brought out through a closed motor frame, they should be felt out by hand, for this is where the confusion is most apt to take place. Wrong internal connections, as far as the man that assembles and sets up the motor is concerned, are confined to the field coils. If a motor has only two field coils and one of them is connected incorrectly, the motor will not start at all unless the starting current is so enormous that the armature itself magnetizes the field. If the motor has four coils and only one of them is incorrectly connected, the machine will start up under excessive current, but will spark badly and acquire a high rate of speed. Compound-wound motors with the series coils connected in to assist the shunt coils will not give the speed regulation that some classes of work require.

62. Mechanical Troubles.—Among the purely mechanical troubles that may interfere with the starting of a motor, the following may be mentioned: *Too much load; loose pole piece down on the core, or bearings worn until core is let down on the pole pieces; sprung armature shaft with the same result; hot box; tight belt; want of end play in the armature; some piece of foreign matter between the core and the pole piece, or between the pinion and the gear, if the motor is geared to its work.* In many cases, a motor can operate many more machines than it can start; it should be a rigidly enforced rule that all machine tools operated by the motor should have their shifters thrown over when the day's work is done. There is no excuse for an armature being let down on the pole pieces through wear in the bearings; they should be closely watched and close track kept of the time of last renewal. A loose pole piece not only restrains the armature mechanically, but it weakens the motor field and lessens the starting power. A sprung armature shaft is liable to occur at any time, and may be due to a suddenly imposed overload, a sudden reversal, or a hot box. A bent shaft is visible to the eye and causes the machine to make a noise. It should be taken out at once. Want of end play may be the fault of the maker or of the operator; on every shaft there are two shoulders that take the thrust of the bearings and limit the end play. Sometimes an armature will turn freely when cold, but when it becomes hot and expands it will bind on the collars. The end play must be limited or there will be knocking, so that if in renewing a set of bearings longer ones are put in than were taken out, the end-play problem is liable to arise. Bearings should always be turned to gauge. Belts should be long enough to allow of sag in the slack side, which should run on top. This improves the area of pulley contact and lessens the tension required to prevent slipping.

SPARKING.

63. Sparking at the brushes may be due to any of the following causes : *Too much load; brushes improperly set; commutator rough or eccentric; brushes making poor contact; dirty brushes or commutator; too high speed; sprung armature shaft; low bearings; worn commutator; short-circuited or reversed armature coil; high-resistance brush; vibration; belt slipping; open-circuited armature; weak field; grounds.*

64. Too Much Load.—In this case the armature heats all over. The sparking may be lessened but not stopped by shifting the brushes ahead on a dynamo and back on a motor. If the machine is a motor, the speed will be low; if a dynamo, the voltage will be below the normal amount. In both cases the pulley is apt to get warm through slipping of the belt.

65. Brushes Improperly Set.—Brushes may be out of their proper position in either of two ways: they may be the right distance apart but too far one way or the other as a whole; this can, of course, be remedied by shifting the rocker-arm back and forth until the neutral point is found. The brushes may, as a whole, be central on the commutator, but too far apart or too close together. Such a fault must be remedied by adjusting the individual holders. On two-pole machines the two sets of brushes are placed diametrically opposite each other. On four-pole machines having two sets of brushes, the distance between the centers of the two sets should be just one-fourth of the circumference of the commutator. On four-pole machines having four brushes, they should set on the quarter; the best and quickest way to get this set in position is to place two sets at diametrically opposite points, the two remaining sets then go half way between them. In any case, for all commutator machines that are not special, the distance between the centers of adjacent sets of brushes should be the total number of commutator bars divided by the number of poles.

66. Commutator Rough or Eccentric.—A commutator will become rough either as a result of abuse or as a result of bad selection of the copper and mica of which it is made. If the mica is too thick or too hard, it will not wear as fast as the copper and will stand out in ridges. If too soft, it will eat out and make a furrow between bars that will catch carbon or copper dust and create local short circuits. An eccentric commutator acts like a bent shaft and may be the result of faulty workmanship or the result of a hard blow. In either case it must be turned true, but before doing it be certain that the commutator is at fault and not the shaft.

67. High or Low Bar.—A high or low commutator bar causes a clicking sound to be emitted whenever it passes under the brush. A high bar can often be removed with a file, but a low bar requires that the whole commutator be turned off.

68. Brushes Making Poor Contact.—Poor brush contact may be due to any one of several causes. The brush may be stuck in the holder; the temper may be out of the tension spring; the brush hammer may rest on the side of the holder and not on the brush; the brush may not fit the surface of the commutator; the holder may have shifted to the wrong angle. New brushes should be sandpapered to fit the commutator; the hammer should rest over the slot that guides the brush, so that when the brush wears it will follow it down. Tension springs should be paralleled by a conductor attached to the brush, so that the current will not flow through the springs and take the temper out of them.

69. Dirty Brushes or Commutator.—Carbon brushes are liable to give out paraffin when hot, which, getting on the commutator, insulates it in spots. The paraffin is also liable to mix with carbon dust and coat the brush with a non-conducting, sticky substance. A copper brush is apt to get clogged with oil, dust, and threads of waste (waste should never be used on a commutator). Brushes should be kept trimmed and cleaned. Dirty commutators, as a rule, are the result of using too soft a brush.

70. Too High a Speed.—A machine is apt to spark if its speed is too high, because it interferes with the commutation.

71. Sprung Armature Shaft. — A sprung armature shaft causes the commutator to wabble, giving very much the same symptoms as an eccentric commutator, and great care must be taken not to confuse a sprung shaft with an eccentric commutator.

72. Low Bearings.—On some types of machine, excessive wear in the bearings throws the armature far enough out of center to distort the field and cause sparking. Modern machines intended to stand fluctuating loads are so designed that there is no danger on this account.

73. Worn Commutator.—When a commutator wears down below a certain point, even if otherwise in good condition, it seems inclined to spark in spite of everything that can be done. It may be because the brushes then span more bars, because the bars become thinner as they wear away, or it may be because an error in the angle of the holder increases with the distance from the commutator. The effect is most noticeable on some street-railway motors where it is almost impossible to run together two motors whose commutators differ greatly in size. The brush holder should be kept as near the commutator as possible, as it not only enables the bars to be counted off more accurately, but it holds the brushes at a short leverage and prevents chattering.

74. Short-Circuited or Reversed Armature Coil. Either of these faults will cause a local current to flow, with the result that either a dynamo or a motor will require an unusual amount of power to run it even when unloaded. The reversed coil can be located by sending current through the coils one at a time and holding a compass over them. A short-circuited coil can be detected by holding a piece of iron up to the head of the armature while it is running; there will be a decided pulsation of the iron once each revolution. Also, a motor will run with a jerky motion especially noticeable at low speeds, and the voltmeter connected to a dynamo will fluctuate. Such a fault may be due to a cross in the coil itself or contact between two commutator bars. In either case, unless the cross is removed, the coil will burn out.

75. High-Resistance Brush.—Up to a certain point, high resistance in a carbon brush is a good feature, and that is why they are used. But it is possible to get the resistance so high that the brush will spark on account of its inability to carry the current at the contact surface. Such a brush will get very hot and will be slowly chewed off at the wearing end.

76. Vibration.—A shaky foundation will cause the whole machine to vibrate and will cause it to spark steadily, which fault can be remedied only by placing the machine upon a firmer foundation.

77. Belt Slipping.—A slipping belt will cause intermittent sparking because it subjects the machine to unusual variations in speed.

78. Open-Circuited Armature.—By an open-circuited armature is meant a break in one of the armature wires or its connections. Excessive current may burn off one of the wires or a bruise of some kind may nick a wire so that the normal load or less burns it off. A commutator may become loose and break off one or more leads. In any case there are two very characteristic symptoms of an open-circuited armature: a ball of fire runs around the commutator and the mica is eaten from between the bars to which the faulty coil is connected, the bars themselves become dark, pitted, and burned on the edges. Sometimes, on account of abuse, the armature throws solder and all the commutator connections become impaired. In such a case there are no actual open circuits, but there are a series of poor contacts that result in making the commutator rough and black, pitting the bars and eating the mica.

79. Weak Field.—A weak field may be due to a loose joint in the iron circuit, to a metallic short circuit in the field coils, to opposition of the field coils, or to the fact that heat has carbonized the insulation on the field coils so that the current short-circuits through it. Any of these influences decrease the number of lines of force that cross the armature, with the result that the starting power of the motor is decreased, and the speed and current are increased. On a dynamo, the E. M. F. and the ability to pick up are decreased.

80. Grounds.—On a metallic-return circuit, a single ground has no effect, but two grounds can so take place that the whole or any part of the field or armature may be cut out; such a pair of grounds is nothing more nor less than a short circuit and it falls under that head. On a ground-return circuit, a ground anywhere except in the armature has, as a rule, but one indication: there is a flash and the armature burns out.

ALTERNATING-CURRENT MACHINERY.

ALTERNATORS.

81. The points given in regard to installing and handling the parts of direct-current machines hold good in regard to alternators. On account of the higher voltages used and the peculiar nature of the alternating current, abrasion of insulation through careless handling is apt to cause more serious trouble than on the lower voltage direct-current devices.

Alternating-current dynamos may be self-exciting or separately excited. As a rule, on account of the flexibility of control they are separately excited from a direct-current machine either coupled to the shaft of the alternator itself or run from an independent agent. In some cases the separate excitation is assisted by a current from the machine itself, this current being rectified by means of a commutator fixed on the shaft. The main and important advantage of separate excitation is that attendants are not called on to handle devices carrying the high voltage of the alternator in their ordinary duties of regulation.

Fluctuations of the voltage may be caused by slipping of the belt of the alternator or that of the exciter. This is one point in favor of directly connected machines with the exciter on the same shaft. All chance of fluctuation due to belt slipping on the exciter is then eliminated. As with any other separately excited machines, the direction of rotation of an alternator is immaterial as far as generation is concerned, but due regard must be had for the brushes on the rings and commutator if the machine has a rectifier.

Where there are two or more alternators to be run in multiple that are not excited from dynamos coupled to their own shafts, it is a good idea to excite them all from the same dynamo. The exciting plant should consist of at least two like units so wired that either can be used, which should be used alternately to insure that both are kept dried out and in good working order. Each alternator field can then be controlled by means of a resistance box in series with it. Alternator armatures are constructed along such simple and substantial lines that they give few of the petty troubles incidental to direct-current practice. Most of the trouble lies in the exciter and its circuit, so that the service of the alternator as a whole is influenced by all the troubles likely to arise in any direct-current circuit. If the exciter is out of order, so is the alternator; if the exciter breaks down, so does the alternator, unless provision is made for quickly throwing in a second exciter. If the exciter belt slips or its brushes spark or either the iron or copper part of the field circuit is impaired, the voltage of the alternator goes down.

Where the machine is alone on a circuit, it is started in the same way as any other isolated dynamo; it is brought up to speed, the field excited by closing the field circuit, and the voltage regulated with the field rheostat. To shut down, the same operations are gone through in the reverse order. Alternating-current machines have a great deal of self-induction; some of them have so much that even on a short circuit the current is not large enough to burn them out. On account of this great self-induction, a dynamo should not be unnecessarily subjected to violent variations in load. For example, if the circuit of an alternator is suddenly opened under full load, the high induced E. M. F. is liable to puncture the insulation and cause a breakdown.

82. Alternators in Parallel.—When alternators are operated in parallel with one another, they must all run at such speeds that their currents will be in step with one another; that is, the several currents must vary in unison with one another, all the currents coming to their maximum values at the same instant. When this condition exists, the machines are said to be *in synchronism;* and before one alternator is thrown in parallel with another, the attendant must make sure that the machine to be thrown in is in synchronism with those already in operation. This is usually indicated by synchronizing lamps or by a synchronizing voltmeter. Some synchronizing lamps are connected so that they go out when the machines are in step, while others are connected so that they light up. The attendant should always be sure as to just which way they are connected before he attempts to throw the machines in parallel. After the alternators are running together smoothly, their loads are adjusted by varying the field excitation.

ALTERNATING-CURRENT MOTORS.

83. Alternating-current motors call for the same general care as dynamos. Like all other dynamo machinery, they must be kept clean. Alternating-current machinery is generally operated at high pressure, and cleanliness is, therefore, absolutely necessary. In stations, it will pay to pipe compressed air to the machines and use a strong blast for blowing the dust and dirt out of the windings. Most of the motors in common use are of the synchronous, or induction, type.

84. Synchronous Motors.—These are the same in general construction as alternators. They are not intended to start up under load, but will run up to speed when connected to the line. In doing so they take a fairly large current, and in some cases, therefore, are brought up to synchronism by some outside source of power—as, for example, a small induction motor—before being connected to the line. Synchronous motors are separately excited and, in fact, are almost the same throughout as a separately excited alternator.

85. Induction Motors.—These motors are used for most work where the motor must frequently be started or stopped or where a good starting effort is required. In fact they are used for about the same kind of work as ordinary direct-current motors. There is nothing about them that requires any special care, that has not already been mentioned, after they are once installed. As a matter of fact, as they are inherently self-starting and have no commutator to give trouble, they require fewer precautions and less judgment on the part of the operator than direct-current machines. At starting there is a tendency to permit an excessive flow of current; this not only strains the machine electrically, but on account of the great armature reaction, which weakens the field, the starting power is also decreased. The starting current is, therefore, limited by means of resistance. This resistance takes either the form of a stationary rheostat placed in the circuit of the armature through collector rings, or it is in the form of a resistance placed within the body of the armature and operated either by means of a lever operating a switch concentric with the shaft or automatically by centrifugal force.

The direction of rotation of a two-phase motor can be reversed by reversing the leads of either phase; that of a three-phase motor by reversing any one of the phases, thereby reversing the magnetic rotation of the field.

86. Many of the smaller sizes of induction motors are started by simply throwing in the main switch, but with the larger sizes, this gives too great a rush of current. When a starting resistance is used, it should be cut out rather slowly in order to give the machine time to gain speed. On the other hand, the starting resistance should not be left in too long, or there will be danger of overheating the motor. Never use a starting resistance for the purpose of regulating the speed. This applies to all motors, direct or alternating. Starting resistances are designed to carry current for a short time only, and if current is allowed to flow through them continuously they will be burned out.

87. Another method of starting induction motors that is used considerably is by means of what is called a **starting compensator.** This is a device inserted between the motor field and the line, and serves to cut down the voltage applied to the motor at starting, thus preventing a rush of current.

Fig. 23 shows the connections for one of these starting compensators. *A* is a double-throw switch, *B*, *B*, *B* the line wires, and *C* the motor. In this figure the arrangement is shown for a three-phase motor. *E*, *E*, *E* are the coils wound on a laminated iron core similar to a transformer core. For a two-phase starter only two coils are necessary. These coils are provided with a number of taps, so that the compensator may be adjusted for different starting requirements. The switch is shown in the starting position, and by following out the connections it will be seen that one section of the coils is in series between the line and the motor field. One circuit, for instance, may be traced from *m* to *s* through *m–n–o–p–r–s*, when the switches are in the starting position. The E. M. F. developed in that portion of the coil between *p* and the adjustable contact *o* opposes, and hence decreases, the line voltage and allows the motor to start up gradually. After the motor is under headway, the switch is thrown up to the running position and one circuit may be traced through *m–n–r–s*. This cuts out the coils and connects the motor directly to the line. The operation of starting usually requires about 15 seconds for motors of moderate sizes. Always be sure that the starting device, no matter what kind it may be, is in circuit with the motor before throwing the main switch.

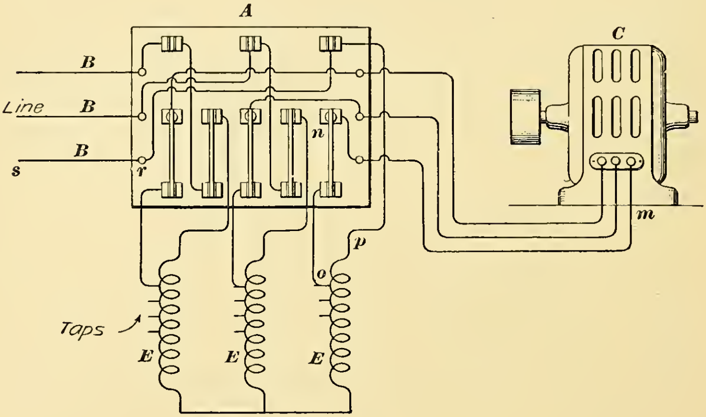


FIG. 23.

ROTARY TRANSFORMERS.

88. Rotary transformers, or converters, are used either to change alternating current to direct current or direct current to alternating. In most cases they are used to change alternating current to direct current, and when used to change from direct to alternating, they are often called **inverted rotaries.**

Rotary transformers combine the features of both direct-current machines and alternators, but on account of their peculiar nature a number of special points come up in connection with them that are not to be found with ordinary direct-current or alternating-current machines. The construction of the machine itself is very similar to that of a direct-current dynamo. The armature is provided with a winding in the same manner as the armature for a direct-current machine and this winding is connected to a commutator. The winding is also connected to collector rings, which serve to deliver alternating current to the machine. For example, when the rotary is used for changing alternating current to direct current, the alternating current is led into the armature winding by means of the collecting rings and is commuted, or changed, to a direct current, which is delivered to the lines attached to the brushes on the direct-current side. If direct current is supplied at the commutator, it flows through the windings and is changed to an alternating current, which is delivered from the collector rings. Rotary transformers when taking current from alternating-current lines run as synchronous motors, i. e., they run in step with the generator that drives them and their speed cannot change unless the speed of the generator changes. They may be run in parallel on either the direct-current or alternating-current sides.

89. Starting Rotary Transformers.—There are a number of different methods used for starting rotary transformers, and the one adopted will depend very largely on the conditions under which the machine is used. The following are some of the methods commonly used:

(*a*) *Starting from the Alternating-Current Side.*—When the machine is to be started from the alternating-current side, the fields are left unexcited and the armature is thrown into connection with the line through a starting resistance. The machine then starts and runs up to synchronism, but in so doing takes quite a large current from the line. The machine starts as an induction motor by virtue of the currents induced in the pole faces by the currents in the armature. After the rotary has come up to speed, the field switch is closed. Another method is to have a small induction motor connected to the shaft of the main machine. This motor is started from the line and runs the large machine up to synchronism. The large machine is then thrown in, and it can thus be started without using an excessive line current. As soon as the rotary is running, it excites its own fields from the direct-current side.

(*b*) *Starting from the Direct-Current Side.*—When a rotary is already in operation in a station and it is desired to start up another, the simplest way is to start up the rotary as a shunt-wound direct-current motor by first seeing that its fields are separately excited and then inserting a resistance in the armature circuit and gradually cutting it out as the machine comes up to speed, like any other direct-current motor. In many stations where storage batteries are used, the rotaries are started by using direct current from the batteries, because they furnish a source of direct current that is always available whether other rotaries are running or not. Another very good method for supplying direct current for starting or exciting purposes is to equip a station with a small direct-current dynamo directly connected to an induction motor. When starting a rotary as a direct-current shunt-wound motor, always be sure that the field is excited before connecting the armature, also see that under no circumstances is the field circuit broken while the machine is running as a direct-current motor. If the above happens, the machine will race, and cases are on record where rotary converters have been almost completely wrecked from this cause. Of course, where the machine is run from the alternating-current end, it runs in synchronism and the breaking of the field circuit will not result in racing. On the whole, however, starting with direct current is the preferable method.

(*c*) *Starting from the Alternator.*—This method of starting rotaries can only be used in comparatively few cases. It consists in connecting the rotary to the line and then starting the alternator in the distant station from which the rotary is operated. As the alternator comes up to speed, so does the rotary. This is a good method where it can be used, and especially where the rotaries are of large size.

(*d*) Another common method of starting is to have a small induction motor attached to an extension of the shaft of the rotary. This motor will start up readily when supplied with alternating current, and after it has brought the rotary up to speed it is cut out.

90. Hunting of Rotary Converters. — Sometimes rotary converters give a great deal of trouble due to what is known as *hunting*. The converter does not run uniformly, but develops a periodic variation in speed that causes wide fluctuations in the direct-current voltage. Excessive sparking is liable to result, and in some cases the effects have been almost as bad as a short circuit. This trouble has been particularly noticeable on converters made to operate at a fairly high frequency, say in the neighborhood of 60 cycles per second. Rotary converters are now generally operated on the lower frequencies, such as 40 or 25 cycles per second. When a machine hunts, the field shifts back and forth across the pole pieces, thus changing the position of the neutral field and giving rise to very bad sparking. The governor on the engine driving the alternator may be responsible for the hunting in the first place, or it may be caused by variations in the load, or by the influence of other machines on the same system. Its effects can be remedied to a considerable extent by putting heavy copper bridges between the pole tips and by surrounding the pole face with a heavy copper ring. If the field then shifts back and forth, it will set up heavy currents in the ring, or bridges, and these currents will tend to oppose any shifting of the field.

TESTING FOR FAULTS.

91. Many of the defects that are liable to arise in connection with dynamos and motors are, of course, apparent from a mere inspection of the machine. Other defects, such as short-circuited or open-circuited field coils, short-circuited or open-circuited armature coils, etc., must be located by making tests. Many of these tests have already been referred to, and the following is intended to show how they are carried out. For tests of this kind Weston or similar instruments are most convenient if they have the proper range for the work in hand. For measuring resistances, the *drop-of-potential method* is generally most easily applied. This method consists in sending a known current through the resistance to be measured and noting the pressure between the terminals of the resistance; in other words, noting the pressure required to force the known current through the unknown resistance. The resistance may then be determined at once from Ohm's law, because $C = \frac{E}{R}$, or $R = \frac{E}{C}$. If the resistance to be measured is very low, as, for example, an armature coil, the voltmeter must be capable of reading low and a millivoltmeter (one reading to thousandths of a volt) will be best suited to the work. Of course, a good Wheatstone bridge may also be used for measuring resistances, but it is generally not as convenient to use around a station as the drop-of-potential method.

92. Testing for Open-Circuited Field Coils.—If a machine does not pick up, it may be due to the absence of residual magnetism. If any residual magnetism is present, a voltmeter connected across the brushes will give a small deflection when the machine is run up to full speed, so that this point can easily be determined before a test is made for a broken field coil. Examination of the connections between the various coils will show if they are defective or loose; quite frequently the wire in the leads from the spools becomes broken at the point where the leads leave the spool, while the insulation remains intact, so that the break does not show. This may be detected by "wiggling" the leads.

If the break is inside the winding of one of the coils, it can only be detected by testing each coil separately to see if its circuit is complete. This may be done with a Wheatstone bridge or with a few cells of battery and a galvanometer. A low-reading Weston voltmeter makes a good galvanometer to use for this purpose.

If the current from another dynamo can be obtained, the faulty spool may be detected by connecting the terminals of the field circuit to the terminals of the circuit of the other machine; no current will flow through if the circuit is broken, but if a voltmeter is connected across each single field coil in succession, it will show *no deflection* if the coil is continuous, because both poles of the voltmeter will be connected to the *same* side of the dynamo circuit. If the coil has a break in it, one of its terminals will be connected to one side of the circuit and the other to the other side, so that a voltmeter connected between these terminals will show the full E. M. F. of that circuit. Consequently, when the voltmeter is connected across a spool and shows a considerable deflection, that spool has an open circuit which must be repaired before the dynamo can operate.

This method of testing is represented by the diagram, Fig. 24; *1*, *2*, *3*, and *4* represent the field coils of a four-pole dynamo, there being a break in coil *2* at *B*. The terminals *a* and *e* of the field winding are connected to the + and − terminals of a "live" circuit; that is, a circuit connected to a dynamo in operation. It will be seen that terminals *a* and *b* of coil *1* are both connected to the + side of the circuit, and as there is no current flowing through the field circuit, there is no difference of potential between *a* and *b*;

therefore, a voltmeter connected to *a* and *b*, as at *V*, will show no deflection. But terminal *c* of coil *2* is connected to the − side of the circuit; so a voltmeter connected to *b* and *c*, as at V_1, will show a deflection, and, in fact, will indicate the difference of potential between *a* and *e*.

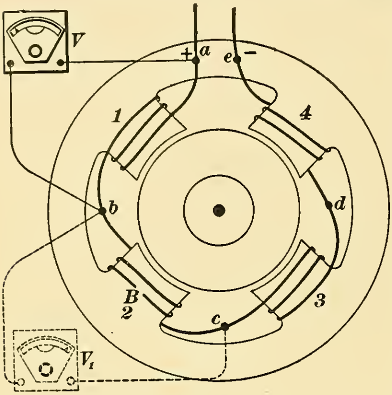


Fig. 24.

The above test may be roughly made with a bit of wire long enough to span from terminal to terminal of a coil. If one end of the wire is touched on *a*, for instance, and the other on *b*, it will not affect the circuit; but if it is touched on the terminals of the coil in which the break is located, the field circuit will be completed through the bit of wire, and a spark will occur when the wire is taken away. The wire should not be allowed to span more than one coil at a time, otherwise it may short-circuit so much of the field winding that too great a current will flow.

93. Short-Circuited Field Coil.—It is evident that if the windings of a field coil become short-circuited, either by wires coming in contact or by the insulation becoming carbonized, the defective coil will show a much lower resistance than it should. The drop of potential across the various field coils should be about the same for each coil, so that if one coil shows a much lower drop than the others, it indicates a short circuit of some kind.

94. Test for Grounds Between Winding and Frame. After the machine has thoroughly warmed up, it should be tested for "grounds," or connections between the winding and the frame or armature core. This may best be done with a good high-resistance voltmeter as follows: While the machine is running, connect one terminal of the voltmeter to one terminal of the dynamo, and the other terminal of the voltmeter to the frame of the machine, as represented in Fig. 25, where T and T_1 are the terminals of the dynamo, and V and V_1 two positions of the voltmeter, connected as described above.

If in either position the voltmeter is deflected, it indicates that the field winding is grounded somewhere near the *other* terminal of the dynamo; that is, if the voltmeter at V shows a deflection, the machine is grounded near the terminal T_1, and *vice versa*. If the needle shows a deflection in *both* positions, but seems to vibrate or tremble, the armature or commutator is probably grounded. If in either case the deflection does not amount to more than about $\frac{1}{20}$ the total E. M. F. of the machine, the ground is not serious, but if the deflection is much more than this, the windings should be examined separately, the ground located, and, if possible, removed.

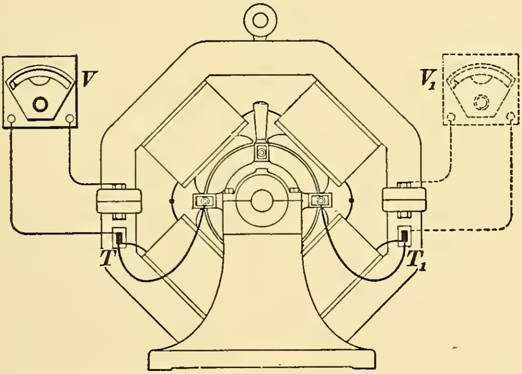


FIG. 25.

95. To locate the ground, if thought to be in the field coils, each coil should be disconnected from its neighbor (with the machine shut down, of course) and "tested out" by connecting one terminal of another dynamo (or of a "live" circuit) to the frame of the machine, care being taken to make a good contact with some bright surface, such as the end of the shaft or a bolt head, and the other to a terminal of the coil to be tested, through a voltmeter, as represented in Fig. 26.

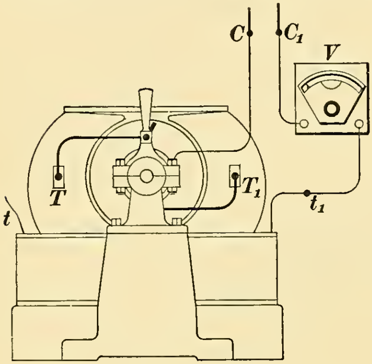


FIG. 26.

Here C and C_1 represent the terminals of a "live" circuit, which should have a difference of potential between them about equal to the E. M. F. of the machine when it is in operation, but not greater than the capacity of the voltmeter will allow of measuring. T and T_1 represent the terminals of the dynamo, as before, and t and t_1, the terminals of the field coils, which have been disconnected from each other and from the dynamo terminals. One terminal C of the circuit is connected to the frame of the machine; the other terminal C_1 of the circuit is connected through the voltmeter V to the terminal t_1 of the field coil. If that coil is grounded, the voltmeter will show a deflection about equal to the E. M. F. of the circuit C C_1, but if the insulation is intact, it will show little or no deflection. The wire connecting the voltmeter with the terminal t_1 may be connected in succession to the terminal of the other coil, or coils, and to the commutator; any grounded coil of the field or armature winding will be shown by a considerable deflection of the voltmeter needle.

96. If the machine tests out clear of grounds, it should be shut down after the proper length of time and the various parts of the machine felt over to locate any excessive heating. If accurate results are wanted, thermometers should be used, placing the bulb on the various parts (armature, field coils, etc.) and covering it with a wad of waste or rags. They should be looked at from time to time until it is seen that the mercury no longer rises, when the point to which it has risen should be noted. A thermometer hung on the wall of the room will give the temperature of the air, and the difference between the air temperature and that of the various parts of the machine should not exceed the prescribed limit.

97. Test for Defects in Armature (Bar-to-Bar Test).—Faults in armatures may best be located by what is known as a **bar-to-bar test.** This consists briefly in sending a current through the armature (in at one side of the commutator and out at the opposite side) and measuring the drop between adjacent bars all around the commutator. If the armature has no faults, the drop from bar to bar should be the same for all the bars. The connections for this test are shown in Fig. 27. *E* is the line from which the current for testing is obtained and *L B* a lamp bank by means of which the current flowing through the armature may be adjusted. Connection is made with the commutator at two opposite points *A*, *B*. A contact piece, or crab, *C* is provided with two spring contacts that are spaced so as to rest on adjacent bars. These contacts are connected to a galvanometer, or

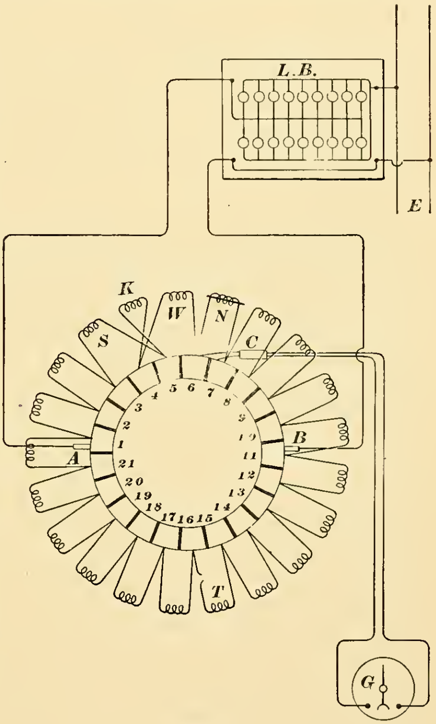


FIG. 27.

millivoltmeter, *G*. For the sake of illustrating the way in which the bar-to-bar test will indicate various kinds of faults, we will suppose that in coil *N* there is a short circuit, that the commutator leads of coils *S*, *K*, and *W* have been mixed, as shown, and that there is an open circuit in coil *T*. Current will flow through the top coils from *A* to *B*, but not through the bottom coils on account of the open circuit at *T*. Terminals *A*, *B* may be clamped permanently in place by means of a wooden clamp, or a strap such as shown in Fig. 28 may be used.

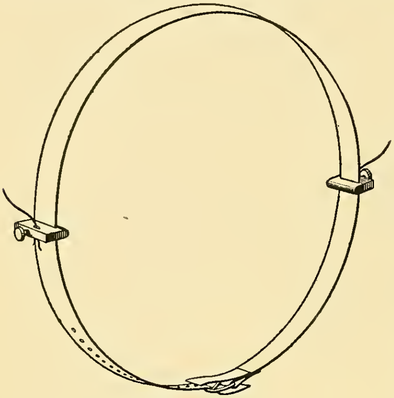


Fig. 28.

98. It is evident that the deflection of the galvanometer will depend on the difference of potential between the bars. If everything is all right, practically the same deflection will be obtained all around the commutator, no matter on what pair of bars *C* may rest. The test is carried out as follows: Adjust the lamp bank until the galvanometer, or voltmeter, gives a good readable deflection when *C* is in contact with what are supposed to be good coils. The amount of current required in the main circuit will depend on the resistance of the armature under test. If the armature is of high resistance, a comparatively small current will give sufficient drop between the bars; if of low resistance, a large current will be necessary. The operator runs over several bars and gets what is called the standard deflection and then compares all the other deflections with this. In case he should start on the damaged part, he will find when he comes to the good coils a difference in deflection.

If the contact rests on bars *3*, *4*, it is easily seen that a deflection much larger (about double) than the standard will be obtained, because two coils are connected between *3* and *4* in place of only one. When on *4* and *5*, the deflection of the voltmeter, or galvanometer, would reverse, because the leads from *K*, *S*, and *W* are crossed. The deflection would not be greater than the standard, because only one coil is connected between *4* and *5*. Between *5* and *6* a large deflection will be obtained for the same reason that a large one was obtained between *3* and *4*. Between *6* and *7* little or no deflection will be obtained, because coil *7* is here represented as being short-circuited and, hence, there will be little or no drop through it. As *C* is moved around on the lower side, no deflection will be obtained until bars *15* and *16* are bridged. There will then be a violent throw of the needle, because the voltmeter will be connected to *A* and *B* through the intervening coils. When *C* moves on to *16* and *17*, there will again be no deflection, thus locating the break in coil *T*. As a temporary remedy for this, bars *15* and *16* may be connected together by a "jumper" or piece of short wire.

99. If any of the coils have poor or loose connections with the commutator bars, the effect will be the same as if the coil had a higher resistance than it should and, hence, the galvanometer deflection will be above the normal. In practice, after one has become used to this test, faults may be located easily and rapidly. It is best to have two persons, one to move *C* and the other to watch the deflections of *G*.

100. Locating Short-Circuited Armature Coils. Where there are a large number of armatures to be tested, as, for example, in street-railway repair shops, an arrangement similar to that shown in Fig. 29 is very convenient for locating short-circuited coils. *A* is a laminated iron core with the polar faces *b*, *b* (in this case arranged for four-pole armatures). This core is wound with a coil *c* that is connected to a source of alternating current. The core is built up to a length *d*, about the same as the length of the armature core. The core *A* is lowered on to the armature, and when an alternating current is sent through *c* an alternating magnetization is set up through the armature coils.

This induces an E. M. F. in each coil; and if any short circuits exist, such heavy local currents are set up that the short-circuited coils soon become hot or burn out, thus indicating their location. If an armature with a short-circuited coil is revolved in its own excited field, the faulty coil promptly burns out, so that this constitutes another method of testing for such faults. To cut out a short-circuited coil, temporarily disconnect its ends from the commutator and bend back the ends out of the way and tape them so that they cannot touch each other and put a short piece of wire, or "jumper," in place of the coil so disconnected. It is always best, however, to replace the defective coil, because if the turns are short-circuited on each other, the coil may persist in heating and thus damage other coils.

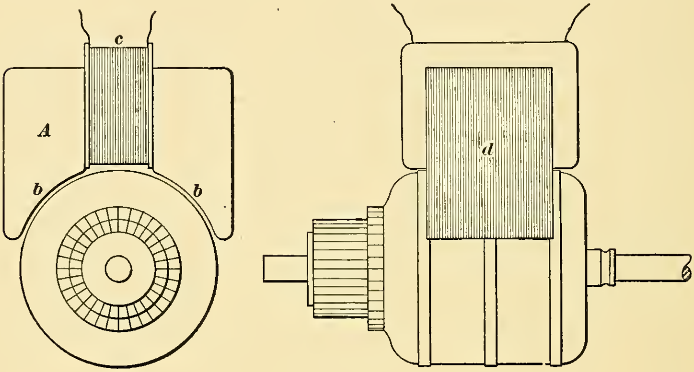


FIG. 29.

RHEOSTATS FOR TESTING PURPOSES.

101. When tests are being made on machines, some form of adjustable resistance is necessary in order to get a variable load. If the current to be handled is not large, a lamp bank is very convenient, since the resistance may readily be changed by cutting lamps in or out. Another very convenient form of resistance for testing purposes may be made by slitting a sheet of ordinary roofing tin into strips, as indicated in Fig. 30, and attaching this sheet to a wooden frame. The strips should be from $\frac{1}{2}$ inch to $\frac{3}{4}$ inch wide, and the sheet should be slit to within $\frac{1}{2}$ inch on alternate edges, so that when it is stretched out and held in position, it will form one continuous conductor. The resistance may be adjusted by a sliding crosspiece *S*, which short-circuits any required amount of resistance. Frames of this kind can be made of different current capacities depending on the width of strip used.

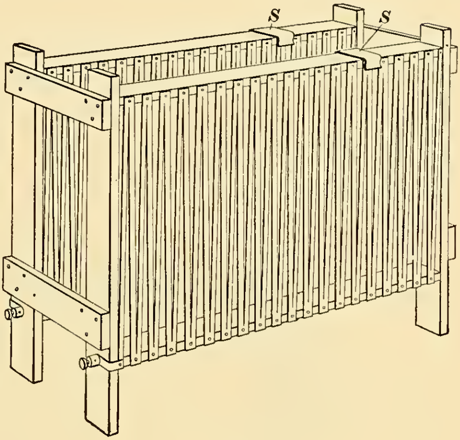


FIG. 30.

102. Water Rheostat.—When heavy currents are to be handled, a **water rheostat** is convenient. This usually consists of a wooden tank filled with salt water, in which are hung two iron (or other metal) plates that are attached to the terminals of the dynamo. The circuit is thus completed through the water between the plates, and, by varying the distance between the plates, the resistance of the external circuit can be adjusted between wide limits.

An old oil barrel makes a good tank if the dynamo to be tested has an output of not more than about 15 kilowatts. If a greater amount of energy must be disposed of, the surface and the amount of the water must be greater than a barrel will afford, and a tank should be made for the purpose, especially if several machines are to be tested. Fig. 31 illustrates a form of water rheostat, in which *T* is the wooden tank, which should be about 7 feet long and about $2\frac{1}{2}$ feet square, inside measurements, made of $1\frac{1}{2}$-inch or 2-inch pine plank, with tongued-and-grooved joints that should be leaded to make them tight, the whole being held together by cross bolts, as represented in the figure.

Two iron rods *R*, *R* are placed across the top of the tank, to which are attached the terminals of the dynamo circuit, as represented at *W*, *W*. From these rods two iron plates *P*, *P* are hung, which should have about $3\frac{1}{2}$ or 4 square feet of surface (on one side) below the water level. These plates may be made of a couple of pieces of old boiler plate or heavy ($\frac{1}{4}$-inch or thicker) sheet iron, cut with two projecting lugs on the top, which are bent into hooks by which the plates are hung from the rods *R*, *R*. Cast iron will do equally well; two old ash-pit doors, for example, will make very good plates, the rods being passed through the holes for the hinge pins. When ready for use, the tank should be filled with water, and from 5 to 20 pounds of rock salt or washing soda added to reduce the resistance to the required figure, as water alone will give altogether too high a resistance.

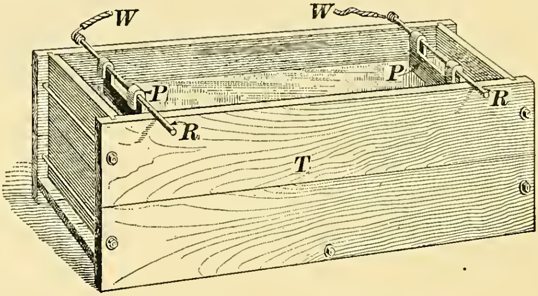


FIG. 31.

ELECTRIC RAILWAYS.

(PART 1.)

INTRODUCTORY.

1. Electricity is now generally conceded to be the most economical agent for the transmission of power for the operation of street railways. It has shown itself superior to horses, compressed air, or cable, both as regards flexibility and cheapness of operation. Cable roads are advantageous in some very hilly localities, but for ordinary traffic even those cable roads already in use are being gradually converted into electric lines. Compressed air has been used in a few cases, notably in mining work, but for general purposes electricity now has the field practically to itself.

METHODS OF SUPPLYING CURRENT.

2. Several different methods may be used for supplying electrical energy to the cars, and the one to be used in any given case is generally fixed by local conditions. The methods that may be used for supplying current to the motors may be classed as follows:

a. By means of an overhead conductor or pair of conductors connected to the car by an under-running contact. This is known as the **overhead-trolley system.**

b. By means of underground conductors run in a conduit and connected with the car by means of a contact plow passing up through a slot. This is usually called the **open-conduit system,** or **slot system.**

c. By means of electromagnetic switching devices that make connection between the car and a conductor situated underground. This is often called the **electromagnetic system.** The conduit in which the conductor is run is, in this case, closed; hence, the name **closed-conduit system** is sometimes applied to this method of operation.

d. By means of a third rail run alongside of, or between, the car rails, contact being made with the third rail by means of a sliding shoe attached to the car. This is known as the **third-rail system.**

e. By means of storage batteries carried on the car. In this case no conductors between the power station and cars are necessary.

3. The overhead-trolley system is the method of operation used in the greatest number of cases, because it is the cheapest to install.

The slot system is used in a number of large cities where overhead wires are not allowed and where the traffic is heavy enough to warrant the expense. It is used, for example, in New York, Washington, Paris, etc., but it is altogether too expensive for the ordinary run of electric railroads.

The closed-conduit system has not yet come into commercial use to any extent. It is expensive to install and is comparatively complicated.

The third-rail method is extensively used for cross-country or suburban lines where the traffic is heavy and where a more substantial construction than the overhead trolley is necessary. It is also used for elevated roads, but is not permissible for surface roads in cities because of the liability of persons coming into contact with the third rail.

Cars operated by storage batteries have never been used very extensively, although they are used in special cases where overhead wires will not be permitted and where the traffic is not heavy enough to warrant the expense of putting down a conduit system. Each car is provided with storage cells, arranged so that they may be easily replaced by fresh ones when they become discharged.

The above methods cover those that, at present, are available for the supply of electrical energy to the motors. We will at this point take up very briefly each of these methods in turn in order to see how the current is supplied in each case. The details by which the methods are carried out will be treated more fully later on, when the subjects of track and line construction are taken up.

4. Overhead-Trolley System.—The general arrangement of the overhead-trolley system is shown in Fig. 1. The positive terminal of the dynamo connects, through the switchboard, to the overhead-trolley wire. The negative terminal connects to the rail. The path of the current is indicated by the arrows. The current is carried to the moving car by means of the under-running trolley wheel, and all the cars on a given system are operated in parallel.

This arrangement, simple as it may seem, was not arrived at before considerable experimenting had been done. In the early electric roads two trolley wires were used, and the track was not employed as one side of the circuit. This scheme is still used in a few places, notably in Cincinnati. Also, on the first roads installed, the trolley wheel ran on top of the wire; but this method of collecting the current was soon superseded by the under-running trolley.

It should also be noted that the cars are operated in parallel. This is true of all systems of distribution where current is supplied to the cars from a central station. All street-railway systems are, therefore, operated at approximately constant potential, i. e., constant or nearly constant pressure is maintained between the trolley wire and the track by means of the dynamos in the station. Whenever connection is made from the trolley to the track through the motors, a current flows and the car is propelled. Each car is independent of the others and takes an amount of current proportional to the power required to drive it.

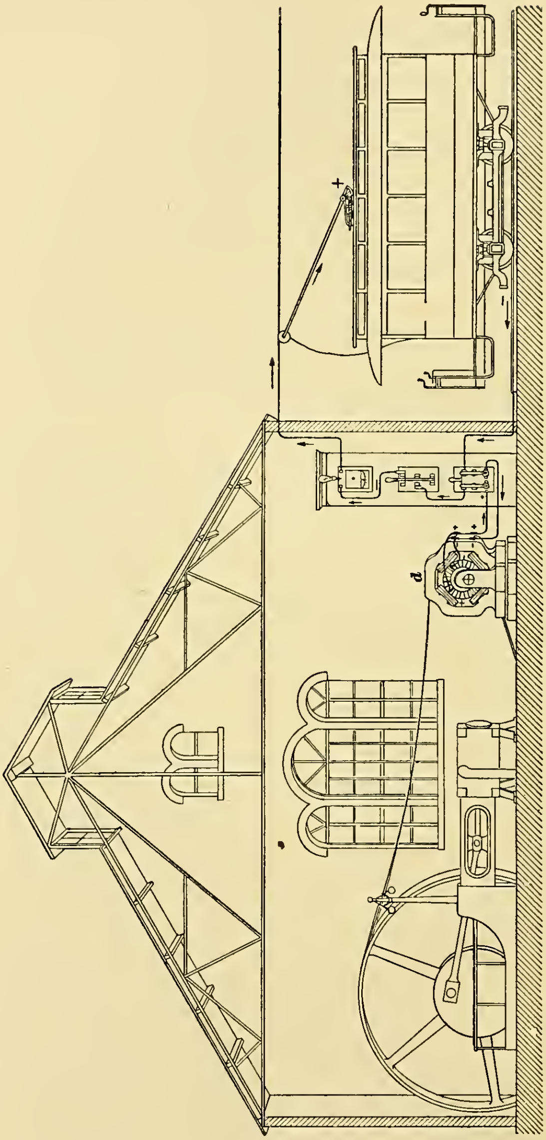


FIG. 1.

5. Schemes have been brought forward from time to time for operating street cars in series, but none of these have ever been put into everyday operation, and it is not worth while devoting space to them.

The arrangement shown in Fig. 1 may of course be modified. For example, except on very small roads, the trolley wire is not sufficiently large to carry the current necessary; so **feeders,** or heavy cables, are run to the station instead of carrying back the trolley wire itself. Also, return cables are sometimes used in connection with the track.

6. The Open-Conduit System.—The open-conduit system has not been put into very extensive use, because the expense of construction is very high compared to the overhead-trolley system. Where it has been installed, it has been a matter of compulsion, the city authorities refusing to allow the stringing of trolley wires and feeders above the surface. Two bare conductors are used, and these are held on insulating supports in the upper part of a channel or conduit, built in the roadway between the car rails, in the same way as a conduit for a cable road. In fact, in several instances the old cable conduit has been fitted up for use as a conduit for railway conductors.

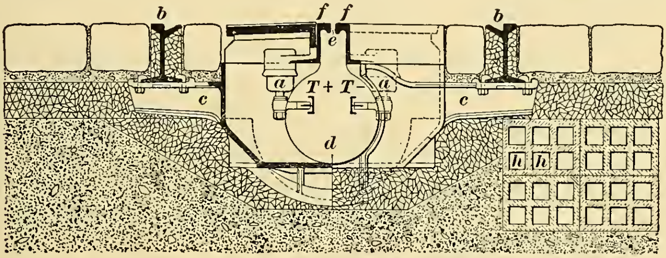


FIG. 2.

The general method of construction, illustrated in Fig. 2, shows the style of conduit used by the Metropolitan Street Railway Company, New York. The rails are supported on cast-iron yokes in place of the ordinary ties, and the conduit extending between these yokes is made of concrete. Concrete is filled in around a sheet-iron form, which is afterwards removed, thus leaving a continuous tube or duct of concrete between the yokes.

In Fig. 2, $T+$ and $T-$ are the conductor rails, which connect through feeders run in the underground ducts *h*, *h*. The track is not used for one side of the circuit, as in the overhead-trolley system. The **T**-shaped conductor rails are attached to insulators *a*, which are, in turn, suspended from the slot rails *f*. Handhole covers are provided at the insulators in order to give access to the insulators and conductor rails.

Fig. 3 shows an enlarged view of a portion of a yoke, showing the method of mounting the conductor rail. The feeders that supply the conductors are buried along the side of the track in terra-cotta or cement-lined tubes. To obviate the necessity of having to raise the paving, more tubes than are necessary to fill the requirements of the present service are put down, so that in the future, when it may be necessary to lay more feeders, there is a place ready for them. To facilitate the installation of new feeders or the repair of old ones, manholes are provided every 400 feet.

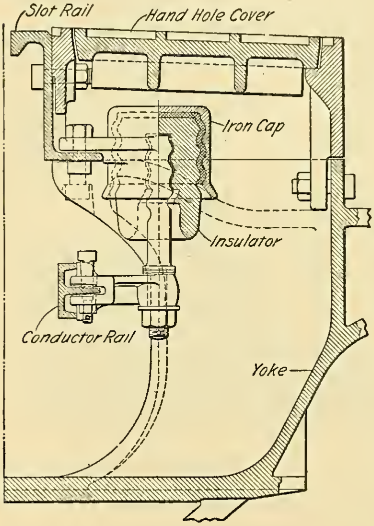


FIG. 3.

Mud accumulates in the main conduit very fast, and if not promptly removed gives trouble. At intervals of 200 feet there are manholes in the main conduit; at the bottom of the manhole is a 6-inch drain pipe leading to the sewer. The main conduit must be cleaned about once a month in the summer time, and perhaps oftener than this during the winter. By means of special scrapers, the mud is drawn into the manhole and is then lifted out and carted away.

7. The conductor rails are not continuous, but are divided into sections about a mile long, and each section is fed by its own feeder from the power house. There is no electrical connection between these feeders, so that the road is cut up into insulated sections, and trouble on one section is not so liable to interfere with the traffic on the others. Each feeder has its own switch and circuit-breaker. In case a ground occurs on one section, the circuit-breaker in the feeder that feeds that section flies out; the attendant in charge at the power house can tell exactly on what stretch of track the trouble is, and notifies the emergency crew to that effect, if it is necessary. Splitting the road into sections supplied by individual feeders has also the advantage that in case of a block on the road, the simultaneous efforts of all the motormen to start their cars will not cause heavy overloads in the power house, because the switchboard attendant has every section of the road under his control and can compel the cars to start up, one section at a time.

8. Fig. 4 shows the style of plow used by the Metropolitan Company. The plow is provided with two iron contact shoes *s*, *s* that press sidewise against the conductor rails *a*, *a* under the action of the flat springs *b*, *b'*. Connection is made to the car by means of cables *c*, *c'*, which connect to the shoes by means of flat insulated strips passing through the flat part of the plow and connecting to the shoes by means of flexible cables *d*. The plow passes between the slot rails *e*, *e* and is securely fastened to a crosshead underneath the car. This crosshead is mounted so that it can move from one side of the car to the

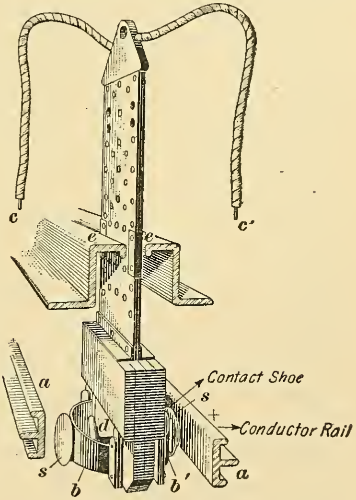


FIG. 4.

other, in order that the plow can change its position relative to the car when necessary.

9. As stated above, the open-conduit construction is very expensive. It is necessary that the yokes be well designed to resist the pressure of the earth (which is packed down by the heavy traffic) and the very heavy pressure in cold climates, due to the freezing of the soil, with its accompanying expansion. Wrought iron, steel, and cast iron have been used for this purpose, the latter, perhaps, being the most used. When yokes of light weight are put in, trouble is often occasioned by breakage. The conduit may be lined with steel plates or it may be constructed on the sides of concrete alone; in some cases the metal yokes have been replaced by concrete, but the best practice is to use heavy castings ranging in weight from 200 to 400 pounds or more, according to the depth of the conduit and the character of the wagon traffic expected.

10. Electromagnetic System.—In this system the regular rails constitute one side of the circuit, and the other side, by means of which the circuit through the car is completed, consists of an insulated third rail split into a number of short sections. These rail sections are supplied with current by successively connecting them to a line conductor run alongside the track.

Fig. 5 will give an idea as to the method of operation. G is the dynamo in the power house. The negative pole of G is connected to the rails t, t_1, as in the ordinary overhead-trolley system. The main conductor m, which is well insulated, is connected to the + side of the generator, and connection is made from it to the sectional rail r r r through switches s, s. The switch is enclosed in a rectangular box located between the middle rail and one of the track rails and is provided with a non-magnetic cover hermetically sealed to prevent water from entering. Directly under this cover and connected to the switch lever are two armatures that are alternately attracted by magnets on the car, one at the front and the other at the rear end, so that any section has current in it only so long as the car is passing over it. For collecting the current a sliding shoe is used.

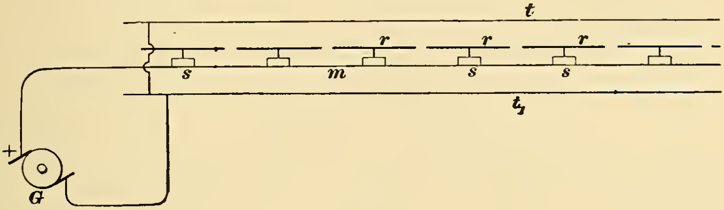


FIG. 5.

A number of other electromagnetic systems have been invented, but so far they have not been adopted very extensively. They have some good points, but these are outweighed considerably by the number of automatic switching arrangements necessary.

11. Third-Rail System.—It is common to hear the third-rail system spoken of as being something comparatively new in the electric-railway line. As a matter of fact, it was one of the very earliest methods used for supplying current to electric cars. One of the first electric roads put into practical operation was at Portrush, Ireland, and was operated on the third-rail system. Of late years the third rail is coming into favor, especially for heavy work. For interurban and elevated-railroad work something more substantial than a trolley wire is required, because the speeds are high and the current to be handled is large. In this system a third rail is mounted, usually at one side of the track, and contact is made with it by means of a sliding shoe carried on the car. The rail is mounted on special insulators and is generally raised somewhat above the other rails. The regular track rails constitute the return circuit. At grade crossings the third rail is omitted, as the momentum of the car is sufficient to carry it over. Of course, the third rail can only be used where there will be no liability of persons coming into contact with it, but for the class of work mentioned above it gives very satisfactory service and its use is rapidly extending. For example, elevated trains in New York, Chicago, and Boston are operated by means of the third rail.

12. Fig. 6 shows a third-rail construction used on the Nantasket Beach and East Weymouth Road. The third rail *r* is, in this case, of special shape, though ordinary **T** rails are often used. The rail shown is made in 30-foot lengths and weighs 93 pounds to the yard. It is shown supported on posts *a*, which are treated with creosote.

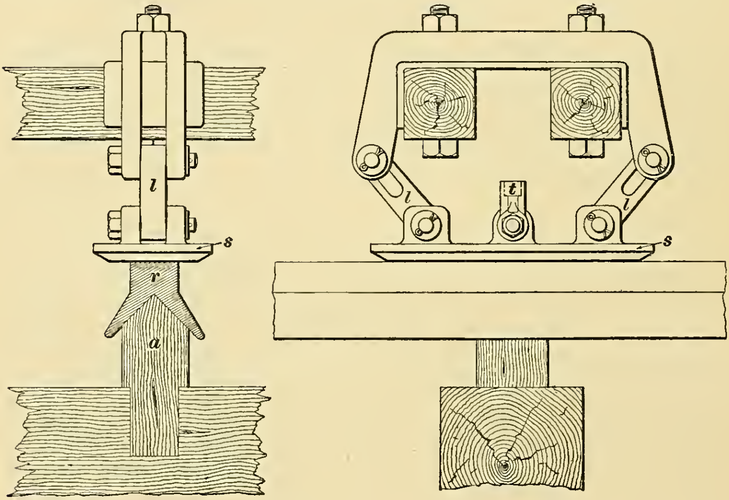


FIG. 6.

Electrical continuity between the rails is secured by fastening them together by copper **bonds.** In the later styles of third-rail equipment, which will be described more fully when track construction is taken up, porcelain or granite insulators are used for supporting the rail.

The shoe *s*, Fig. 6, slides on the rail and conveys the current to the car by means of a cable fastened to the terminal *t*. The slotted links *l* allow the shoe to play vertically, so as to follow inequalities in the track. There are two contact shoes and frames to each car on this particular road and they are placed 33 feet apart, so that at road crossings the third rail may be omitted and the momentum of the moving car depended on to carry it over. When the width of the road is less than 33 feet, there is no break.

CURRENT SUPPLY.

13. Direct Current vs. Alternating.—Electric street cars are operated almost wholly by means of direct current. This means that the current actually supplied to the motors is direct, although the current generated in the central power station may be alternating. The reason for this is that the alternating-current motor has not as yet proved as reliable for this class of work as has the direct-current motor. It must be remembered, however, that alternating-current induction motors have been making rapid advances, and some railroads in Europe are at present operated by them. It is not at all improbable that in the future alternating-current motors will be more used on electric cars, but the practice so far in the United States has been to convert the alternating current into direct current by means of rotary transformers and to use direct-current motors on the cars rather than to supply the alternating current directly to induction motors.

Induction motors, if properly designed, can be made to give a strong starting effort, which is one thing very necessary in a street-car motor. Three-phase motors have been used on what few roads have been equipped with alternating-current apparatus. The three-phase system requires three wires, and as the track answers for one of them, two overhead wires are needed. This complicates the overhead construction and has been brought forward as one argument against alternating-current motors for street-railway work.

While alternating-current motors themselves have not made very great headway in street-railway work, the use of alternating current at high pressure as a means of transmitting the power has come into much favor, because it allows the cars to be operated from a central station situated some distance from the point where the power is used.

14. Voltage.—The pressure at which current is supplied to the cars is limited by considerations of safety. It would, of course, be desirable to use a high pressure, because this would mean a small current for a given amount of power, and small feeders would be sufficient. However, a pressure is soon reached where it would be decidedly dangerous to life, and for this reason the working voltage on street railways has been fixed at about 500 volts. On some suburban lines the pressure runs over 600 volts, and again in other places it will be found much lower than 500 volts, on account of an excessive drop in the line. Railway motors and other apparatus are designed for 500 volts, and the pressure on the line should be maintained at or near this point. Low voltage requires a correspondingly large current to supply enough power to operate the cars at the required speed; hence, if the pressure is lower than normal, heating of the motors is liable to result.

THE POWER HOUSE.

15. In considering electric railways in detail, it will be convenient to divide the subject into three parts, as follows: (*a*) the *power house;* (*b*) the *line and track;* (*c*) the *car equipment.*

We will take these up in their order, beginning with the power house and the apparatus with which it should be equipped.

LOCATION OF POWER HOUSE.

16. General Considerations.—The **power house,** or **power station,** as the name implies, is the place or source of supply of power for running the cars, and it should be situated as near the center of the system as possible. By the center of the system is meant the center of the load or traffic. In other words, since wires must be used to convey the power from the power house out to the point where it is to be used, a part of the power generated will be lost in these wires, because they always have some resistance. If the line wires are not of sufficient size, they will cause a loss of power that will make itself very strongly felt in its effect on the speed that the cars make and also upon the amount of heat that the motors develop. Laying other things aside for the present, the amount of loss in one of these supply wires depends on its length and on the amount of current that it may be called on to carry. Hence, it follows that the center of the load may not be the geographical center of the system. As a matter of fact, these two centers very seldom fall in the same place. The true load center is located in the same way that the center of gravity of any system of bodies is located. The geographical center, as we have called it, depends on the number of miles of track and how these are disposed; the other depends on how the load is distributed.

In Fig. 7, *A B* represents 10 miles of track free from grades and sharp curves, and on this track a certain number of cars *1*, *2*, *3*, *4*, etc., of about the same weight and equipped with motors of the same size, run at regular intervals. It is easily seen that the geographical center, or center of mileage, is in this case located at *P*, a point midway between the two ends, so that there are 5 miles of track on each side of it. It can also be shown that the load center in this particular case is also at *P*; for, suppose that all the cars, except the two on the extreme ends, are running at full speed. Since the track is level and the cars and motors are alike, they will all take about the same power, and since the loads are evenly distributed throughout the length of track, they can be represented by circles of the same size, as shown in Fig. 7. Here, there are seven loads on each side of the center line passing through *P*, and if each circle is supposed to represent a weight of a certain number of pounds, and the center of gravity of the system of weights is to be determined, it will be found to fall on the center line *c l*. So also, if all cars, except the two end ones, are supposed to stand still or to coast along with the power off, and the two end ones start at the same time, the same load will be drawn to both ends of the line, and point *P* will still be the center of load and will therefore mark the spot where the power house should stand.

It is not intended to convey the idea that the load, even on such a simple layout, will always be as evenly distributed as has been supposed in this ideal case, for, as a matter of fact, such a condition will be the exception rather than the rule. Suppose *A* to be in the outskirts of a large city and suppose *B* to be down-town, where the people must all go to business; then, in the mornings and evenings, when the crowd is going to and coming from work, the load leans a little towards the *B* end of the line, but during the rest of the day it is uniformly distributed. To alter conditions, suppose that from the middle of the line to *B* there is an up grade. It is easily seen that those cars that are ascending the grade will be called on to do more work than those on the level and on the down grade, so that the final effect will be to shift the ideal site for the station towards *B*. In this case, the mileage center remains the same, but the load center is changed.

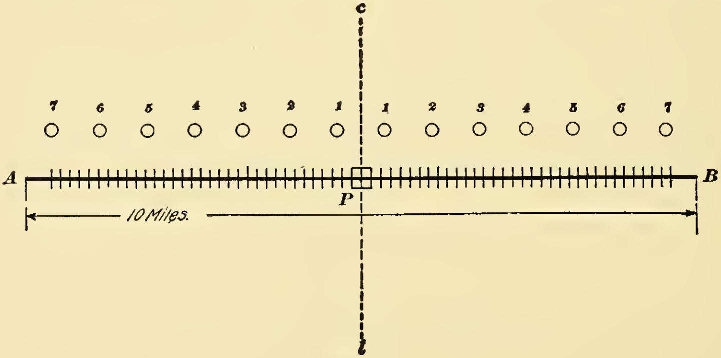


FIG. 7.

17. Influence of Future Extensions. — In locating the site for the power house, future extension and increase in traffic incidental to the development of outlying districts should be borne in mind and the site selected accordingly. Long experience and computation have proved that it is not profitable, with the ordinary direct-current, 500-volt transmission, to operate cars at points more than 7 miles from the house, because, in order to keep the line loss down to a reasonable amount, the feeders must be so large that their cost becomes excessive.

Suppose, for example, as shown in Fig. 8, that the full-line section *A B* represents the stretch of track put down at the first building of the road and that, in accordance with the demand at that time, the power house was put at *P*, the center of load for *A B*, which is supposed to be level.

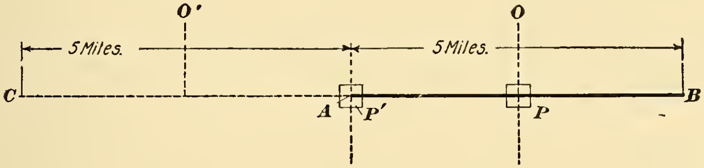


FIG. 8.

Now, suppose that the road has been extended out to a point *C*, so that $AB = AC$. If we further assume that the district through which *A C* runs becomes built up, it will be only a matter of time when the travel density will be as great on the new stretch of track as it is on the old, in which case, assuming the different load units to be fairly evenly distributed throughout the distance *B C*, the proper place for the power house would be at point *P'*, midway between *B* and *C*, the two ends of the road.

For, suppose $BC = 10$ miles; then will $AC = AB = 5$ miles, and $PA = PB = 2\frac{1}{2}$ miles. As long as *A B* constituted this whole road, the power house situated at *P* was at the center of an evenly distributed load, and the same loss of power would attend the transmission of a given amount of power to one end of the line as to the other.

As soon, however, as the extension *A C* is started, it is not a difficult matter to see that a power house at *P* would be 2½ miles from the *B* end of the road and *C A* + *A P* or 7½ miles from the *C* end of the road. Under such a condition, should all the cars, through trouble of some sort, become congested at the far end of the line, the line loss incidental to the great distance and to the large current caused by trying to start all the cars at once would seriously delay getting the cars on their time again. By moving the station to *A*, matters will be righted.

If the station were put at *A* in the first place, it would, of course, be at one end of the line as long as *A B* were the whole road, and would not therefore be at the center of load; but if the extension *A C* is only a matter of time, it will be far the better plan to put up with the line loss due to want of balance on the shorter line, locate the station at *A*, and be prepared to get the best results when the extension is in operation and the number of cars, therefore, greater.

18. If, in deciding the best location for the power house, it were only a matter of fixing the probable center of load, the problem would be a comparatively easy one. In many cases, as we shall see later, the problem is an easy one; but in other cases it is made very hard and almost impossible to solve, except approximately, by the fact that several other considerations have a great influence on the location. The prospective center of the load might be located under conditions that point with absolute certainty, from a purely electrical point of view, to the desirability of a certain place as a site for the power house; at the same time, this place might prove to be so situated that every pound of coal to be burned under the boilers would have to be hauled to the power house. Again, the center of load might fall at a place where it would be difficult to get water for the boilers and the condensers; such a place would, of course, be out of the question. Finally, the question of land comes in. It would be a very poor move to build a power house in a part of a city where a city building would probably pay as good dividends as many well-managed roads. In such a case, then, there must be a careful comparison made between what an improved building on the proposed site would pay and what the annual power loss would be as a result of selecting some other power-house site electrically not as good as the center of load. It can be seen, then, that the final selection of a site for the power house must, in some cases, be a compromise between conflicting conditions. Load conditions will point to one site; good, cheap water and plenty of it will point to another site; the coal bunkers should be arranged so that the coal may be passed directly to them from the boat, or at least from a coal car that can be run alongside of them by means of a siding or a spur from the main line. Very often a point can be selected to fulfil all these conditions; but just as often it is necessary to select a compromise that will be fair to all of them. It is not hard to see, therefore, that the proper solution of the problem may require a great deal of study, work, and experience.

DETERMINING THE LOAD CENTER.

19. In illustrating the method used for obtaining the load center, we do not intend to deal with roads that require the equalization of the advantages incidental to the above limiting conditions. Such a consideration involves details that are beyond the scope of this Course; also, the conditions vary so widely that it is almost impossible to lay down any rules that can be applied with safety in particular cases. We shall assume, therefore, that in all cases the layout of the road is along the lines shown in the diagrams, and that, as there are no limitations imposed by coal, water, and property requirements, the selection of a site for the power house resolves itself to the determination of the load center. To find the load center, the engineer must have a knowledge of the traversed district. With this knowledge in hand, the problem can be treated graphically, and it amounts to the same thing as finding the center of gravity of a system of bodies. As an example, in Fig. 9, W and W' are two bodies whose centers are 11 feet apart, and each of which, for example, weighs 20 pounds. Since, in this case, the two weights are equal, the distance of their centers from the center of gravity P must also be equal, in order that $W \times l$ shall equal $W' \times l'$. The center of gravity is, therefore, midway between the two bodies, and the system, as a unit, acts the same as if a weight of 40 pounds were fixed at P.

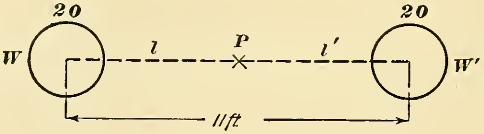


FIG. 9.

20. Finding the center of gravity of W and W', in Fig. 9, amounts to about the same thing as finding the center of load or the location of the power house in Figs. 7 and 8. Take Fig. 8, for example. The load is supposed to be uniform over the two sections $A\,B$ and $A\,C$. Let $A\,B = A\,C = 5$ miles. Suppose that there are 10 cars on each section and that each car averages a load of 20 horsepower. Each section will, then, carry a load of 200 horsepower, and all this load can, in each case, be supposed to be concentrated at points O and O' in the center of the respective sections. These centers, will, therefore, be $\frac{1}{2}\,A\,B + \frac{1}{2}\,A\,C$ miles apart; that is, 5 miles apart. The two loads of 200 horsepower concentrated at points O and O' in Fig. 8 correspond to the two weights of 20 pounds in Fig. 9, and if we treat the 200 horsepower as weights and find their center of gravity, that center of gravity will be the center of load or the correct location for the power house. Since the two loads or weights are equal, the center of gravity or load must, as in Fig. 8, be at point A, midway between O and O'

21. Take another case. Suppose that there are three weights (Fig. 10): $W = 40$ pounds; $W' = 50$ pounds; and $W'' = 10$ pounds; further, suppose that the distance from W to W' is 6 miles; from W to W'', 7 miles; and from W' to W'', 4 miles. Where is the center of gravity situated? The way to ascertain this is to first find the center of gravity between any two of the weights, and then, supposing the sum of the two weights to be situated at this point, to find the center of gravity between this and the third weight. Let us first find the center of gravity between weights $W = 40$ and $W'' = 10$, where the distance between centers is 7 miles. This distance of 7 miles must be divided into 2 parts, such that $W \times l = W'' \times l''$, where l and l'' are the distances of W and W'', respectively, from the center of gravity for these two bodies. To solve the problem graphically, lay out the plan to scale on paper; that is, represent the 7 miles by 7 inches, and so on, and let a difference in the sizes of the circles represent the difference in weights, as shown in the diagram. Call L the distance from W to W'', and let the distance from W to the center of gravity, to be found, be represented by l; then the distance of W'' from the center of gravity will be represented by the difference, or $L - l$; and since $W \times l = W'' \times (L - l)$, we have $Wl = W'' L - W'' l$, or $W'' L$

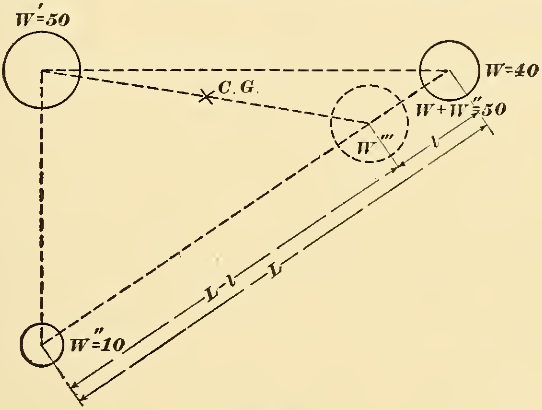


FIG. 10.

$= W l + W'' l$, and $l = \frac{W'' L}{W + W''}$. Substituting for the weights and for L the numerical values given, we have $l = \frac{10 \times 7}{50}$ $= 1\frac{2}{5}$ miles, or inches on the paper, as the distance of the weight W from the required center of gravity. Since the total distance $L = 7$, the distance from the center of gravity to the center of W'' must be $L - l$, or $5\frac{3}{5}$ miles. Now take a pair of dividers and a scale and on the line joining the centers of W and W'' locate a point that is $1\frac{2}{5}$ inches from the center of W; this is the center of gravity sought, and it will be $5\frac{3}{5}$ inches from the center of W''.

It is now in order to find the center of gravity between the large dotted circle, representing the combined weights (50 pounds) of W and W'', situated at their center of gravity, and W', which is also 50 pounds. Call the dotted circle W'''; since the weights W''' and W' are the same, it is evident that their center of gravity is midway between them on the line joining their centers, so that it is only necessary to take a pair of dividers and bisect this line in order to find the center of gravity of W' and W''', and hence of the whole system.

22. Conclusion.—The general rule, then, for locating the center of load or the best position for the power house is as follows: Divide the line of the proposed road into several sections; with a knowledge of the service to be rendered on the road, assign a certain load in horsepower, kilowatts, or amperes to each section. Lay out, to scale, a plan of the road on paper. Suppose that the load assigned to each section is concentrated at its middle point; there will then be as many of these points as there are sections, and each point will bear a number designating the load on the section of which that point is the center. The numbers can be considered as representing weights and the center of gravity of all of them determined as shown in the preceding articles. The center of gravity so found will be the load center that marks the best location for the power house.

STATION EQUIPMENT.

ENGINES AND BOILERS.

23. The type of engine most suitable for use in a railway power station depends on the size of road, that is, on the number of cars in regular operation. The closest speed regulation under widely varying loads is obtained with high-speed, automatic cut-off engines, and this class is, therefore, particularly suitable for very small roads. It is easily seen that such a road furnishes extremes of load at very short intervals of time, for if there is only one car in service, the station load, except for the friction losses, field exciting currents, and a few lamps, is zero when that one car is at rest or on a down grade, and is at a maximum when the car is starting on a steep up grade. When a second car is added to the service, the chances are less that such extreme variations will occur, and the more cars that there are in service, the nearer will the load approach something like a constant normal value. The more cars that there are, the less probable is it that all of them will be taking no power at the same time, so that the station is under a certain amount of load all the time. It does not matter how large the output of the station may be, the load fluctuations will be sudden and violent; but still, if the station is large, a given variation in the load is a smaller percentage of the total load and is, therefore, not felt as much on the generating and regulating devices. On stations of any size, the load, as a rule, has several high values during a day of 24 hours. The two greatest values occur in the morning, when the people are going to work, and at night, when they are coming from work. Around noon and on towards 2 o'clock, when the shoppers begin to move, the load is again above normal. The time of occurrence of maximum and minimum loads depends a great deal on local conditions; it is different on different roads, and sometimes on the same road it differs from day to day.

24. As stated above, high-speed, automatic cut-off engines are suitable for small roads where the load fluctuates rapidly. Mine-haulage plants, for example, are usually of this class. On most roads, however, it has become the practice to use slow-speed engines of the Corliss type, especially when the load is moderately large. In moderate sized stations, where space is not scarce, belted dynamos are used. These machines are usually driven directly from the flywheel of the engine. The station is made up of a number of units, each consisting of an engine belted to its dynamo. Countershafts are not now used to any extent in railway plants, the tendency being rather to split the station into a number of distinct units. When the units are very large, and also in case space is limited, direct-connected engines and dynamos are to be preferred. In some of the largest stations, vertical Corliss engines are used, and these are generally of the compound or triple-expansion type. The first cost of a direct-connected dynamo is greater than a belted one for the same output, but the saving in space and absence of belts go far to compensate for this and account for the rapidly increasing use of direct-connected units. When this class of machinery was first used, trouble was caused in some instances by magnetic leakage. This magnetized the shaft and bearings in such a way as to cause a lateral thrust on the shaft and give rise to hot bearings. In the later styles of machines, the design in this respect has been so improved that this trouble has been done away with to a large extent.

25. On most large direct-connected railway sets using slow-speed engines, a heavy flywheel is provided. The fact that the steam and electric units are rigidly connected and that the dynamo armature has great inertia complicate the conditions in case of an excessive overload due to a short circuit or other abnormal condition on the line, because, in the case of a short circuit, there is nothing to finally relieve the strain on the dynamo should the circuit-breaker fail to open the circuit at once. With a belted unit, an excessive load causes the belt to slip—a clutch will act in the same way—so that a belt or clutch acts as a kind of mechanical safety device to cushion the shock that the dynamo gets in case of a sudden overload. On the whole, however, everything is in favor of the direct connection, due precautions being taken to see that the circuit-breaker is set at a safe load and that it is in a condition to work at the load for which it is set. Generally speaking, very heavy flywheels should be used on engines for running street railways. The whole engine construction must be of a very substantial character, because it must be remembered that the load is much more liable to severe fluctuations than with electric lighting or ordinary power transmission work.

26. Size of Engines.—The size of engines and dynamos for different station units will, of course, depend largely on the total output of the plant. In general, it is not a good plan to have a large number of small units, but on the other hand, it is not economical to have only one or two large units, because under such circumstances, even if only one of these units were operated, it would be run on a load much below its capacity, and hence would operate at a low efficiency. The units should be arranged so that they may be kept loaded up to nearly their capacity. In most of the recent plants the units are of the same size and type, because a small stock of repair parts is then sufficient for the station. It is always an advantage to have the machinery in a station uniform, even if it is necessary to sacrifice a few advantages in other directions to attain this end.

27. Steam Piping.—What has been said with regard to steam piping for electric plants in general applies also to street-railway power houses. In some cases, duplicate steam piping is used to avoid shut-downs in case a break occurs, but in some of the largest and most modern power stations, duplicate piping is not used. The single piping is installed in a very substantial manner and with a large margin of safety, so that the chances of a breakdown in the piping system are very small. Duplicate piping is complicated and expensive, and for this reason there appears to be a tendency to revert to the single piping and to install this in such a way that it will be able to meet all demands made on it.

28. Condensers.—The engines should, when possible, be run in connection with condensers. These condense the exhaust steam, instead of allowing it to exhaust into the air, and thereby create a partial vacuum behind the piston of the engine. This increases the effective pressure on the piston and results in a saving in fuel. Jet condensers are most commonly used in power plants. In this type the exhaust steam is condensed by being brought into contact with a jet of cold water. This of course heats the water, and if provision is not made for a fresh supply of cold water, the warm water must be cooled before it can be used over again. The warm water is pumped out by means of the air pump, which also carries out any air that may be mixed with the water.

This air pump, in large stations, is usually independently driven by an engine of its own. For smaller stations, it is generally arranged like a direct-acting steam pump, or else it is operated from the steam engine itself. In some instances, the air pumps and boiler-feed pumps are driven by electric motors.

29. Cooling Towers.—In many places it is not possible to get sufficient water to operate condensers without going to great expense. This is usually the case where the plant cannot be situated on a water front and where all the water used must be bought. Where the water supply is limited, **cooling towers** are used to cool the condenser water and enable it to be used over again. These are made in a number of different ways, but in most cases the water is cooled by allowing it to drop from the top of a tower in a thin sheet so that it will be exposed to the air. Sometimes the water is allowed to fall through a current of air set up by fans; in other cases, requiring a longer tower than the former, no artificial draft is used. In either case, the comparatively rapid evaporation of the water results in its being cooled enough so that it can be used over again.

30. Boilers.—The boilers used in railway plants are generally either of the return-tubular or water-tube type. In the former, the hot gases pass through flues or tubes surrounded by water, while in the latter the water is in tubes and the gases pass around them. The ordinary return-tubular boiler is low in first cost, is easy to keep in repair, and has given excellent service in many places. The water-tube type is, however, very largely used, because of its safety and because it can make steam very rapidly if occasion demands it. Both types of boiler have their good and bad points, and both are extensively used. Where space is scarce, vertical boilers may be used to advantage.

31. Fuel Economizers.—In places where coal is comparatively expensive fuel economizers are used. These are intended to heat the feedwater before it passes into the boilers by making use of the heat contained in the hot gases which would otherwise pass up the stack. The feedwater is circulated through a large number of tubes, which are so arranged that the hot furnace gases pass around them on their way from the boilers to the stack. By this means, the feedwater may be heated to a temperature much higher than when an ordinary exhaust steam heater is used.

32. Conveyers.—For large stations, coal and ash conveyers should be provided. The coal conveyer is usually arranged to take coal directly from the car or barge and carry it to the coal bunkers above the boilers. The ash conveyer runs along under the ash-pits, so that, as the ashes are dumped down, they are carried out. In small plants, conveyers are not, as a rule, provided, at least not on an elaborate scale, because the amount of coal and ashes to be handled is comparatively small. In large stations, mechanical stokers are used for firing the boilers.

33. Example of Station.—Fig. 11 shows a cross-section of the power station of the South Side Elevated Railway Company, of Chicago, and will serve as a typical example of a modern power house of comparatively large capacity. The station, like nearly all power houses, consists of two large

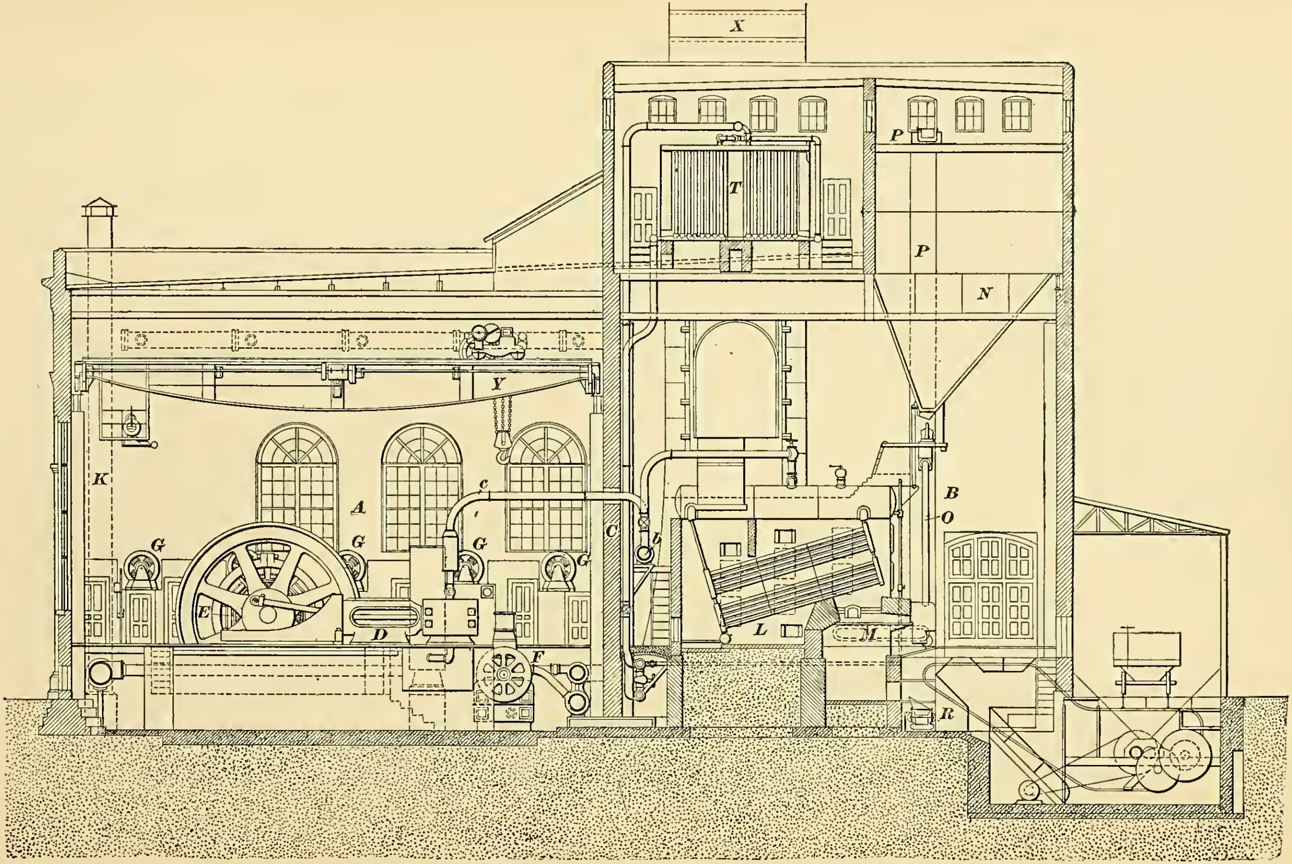


Fig. 11.

rooms—the engine room *A* and the boiler room *B*—separated by a brick fire-wall *C*. Each of the engines *D* is of the cross-compound Corliss type and is coupled directly to its dynamo *E*. These engines are especially heavy and are rated at 1,200 horsepower each; they can, however, develop 2,000 horsepower if necessary. The generators *E* are of 800 kilowatts capacity and have 12 poles. They also will stand a heavy overload without damage. The exhaust steam from the engines passes to an independently driven jet condenser *F*, and the condensing water is cooled by means of a cooling tower placed outside the building. The cooling tower is divided into sections, and each section is provided with fans driven by the motors *G*, which are inside the building. If necessary, the engines may be allowed to exhaust into the air through *K*. The boilers *L* are of the water-tube type and are fed by chain-grate stokers *M*. Coal is supplied to the boilers from the bunkers *N* through the chutes *O*. The bunkers have a storage capacity of 1,000 tons, and are filled by means of the conveyer *P*, which carries a continuous chain of buckets and passes up the side of the plant, across over the bunkers, along under the ash-pits, and up the other side of the plant, thus forming a continuous chain. The coal is delivered to this conveyer by a second conveyer *R*, which takes it from the car. A fuel economizer *T* is used, so that the hot gases on their way to the stack *X* may be used to heat the feedwater. All the steam pipes from the boilers run to the main pipe *b*, from which run the steam pipes *c* to the different engines. The dynamo room is provided with an overhead electric traveling crane *Y*, to be used in placing or repairing the engines and dynamos.

ELECTRICAL EQUIPMENT OF STATION.

34. The electrical equipment of a power house may be conveniently divided into two parts: the part that generates the power and the part that is used to control its distribution to the point where it is used. The first part includes the **dynamos**, or **generators**, as the dynamos are commonly termed when used for railway work. The second part includes the **switchboard**, with all its devices for controlling and measuring the current sent out on the line.

DYNAMOS FOR RAILWAY WORK.

35. The dynamos used for railway work are in general the same as those used for lighting or power distribution.

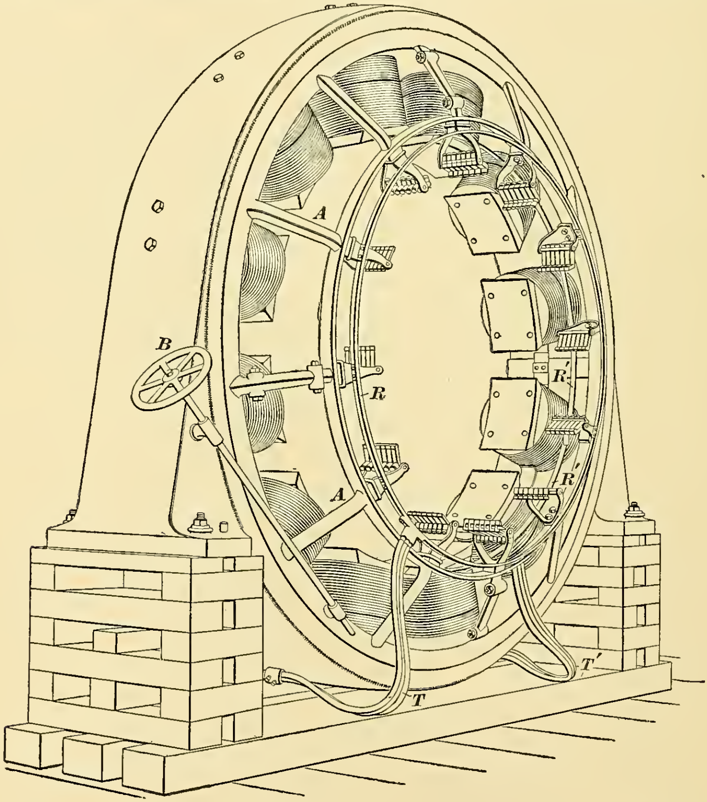


FIG. 12.

They should be exceptionally well built, so as to withstand the sudden strains thrown on them, and should be capable of handling a considerable overload for short periods without excessive sparking or heating. Whether direct- or alternating-current generators are used will depend on the system of distribution adopted. When the power must be carried for long distances, the best plan is to install high-pressure alternating-current generators to supply current to substations located at various points on the system. In these substations the alternating current is changed to direct current by passing it through rotary converters.

In the great majority of cases, however, direct-current generators are used, and these supply current at a pressure of from 500 to 600 volts directly to the feeding system.

36. Direct-Current Generators.—These machines may be either direct-connected or belt-driven. The former type is now installed in most new stations, especially where the units are fairly large. Fig. 12 shows the field frame, with the field coils in place, for a typical 650-kilowatt direct-connected generator. Compound-wound dynamos are used almost exclusively for railway work, and the reasons for their use will be seen later. Each of the field spools is provided with two windings, a series and a shunt, as indicated in the figure. The brush holders, of which there are as many sets as there are poles, are carried by the frame *A A*, which is fitted into the field casting so that it may be revolved through a small arc by turning the wheel *B*, thus allowing the brushes to be adjusted to the point on the commutator that gives the least amount of sparking. Alternate sets of brushes connect to the rings *R*, *R'*, and to these rings the main armature cables *T*, *T'* are attached.

37. Fig. 13 (*a*) and (*b*) gives two views of a typical armature for a direct-driven railway generator. It will be noticed that the construction is very substantial and that the commutator *A* is of ample proportions. The conductors on the armature are in the shape of rectangular copper bars, which are sunk into slots in the periphery of the iron core. The ends of these bars, seen projecting at *a*, *a* on the commutator end, are connected to the commutator bars by the

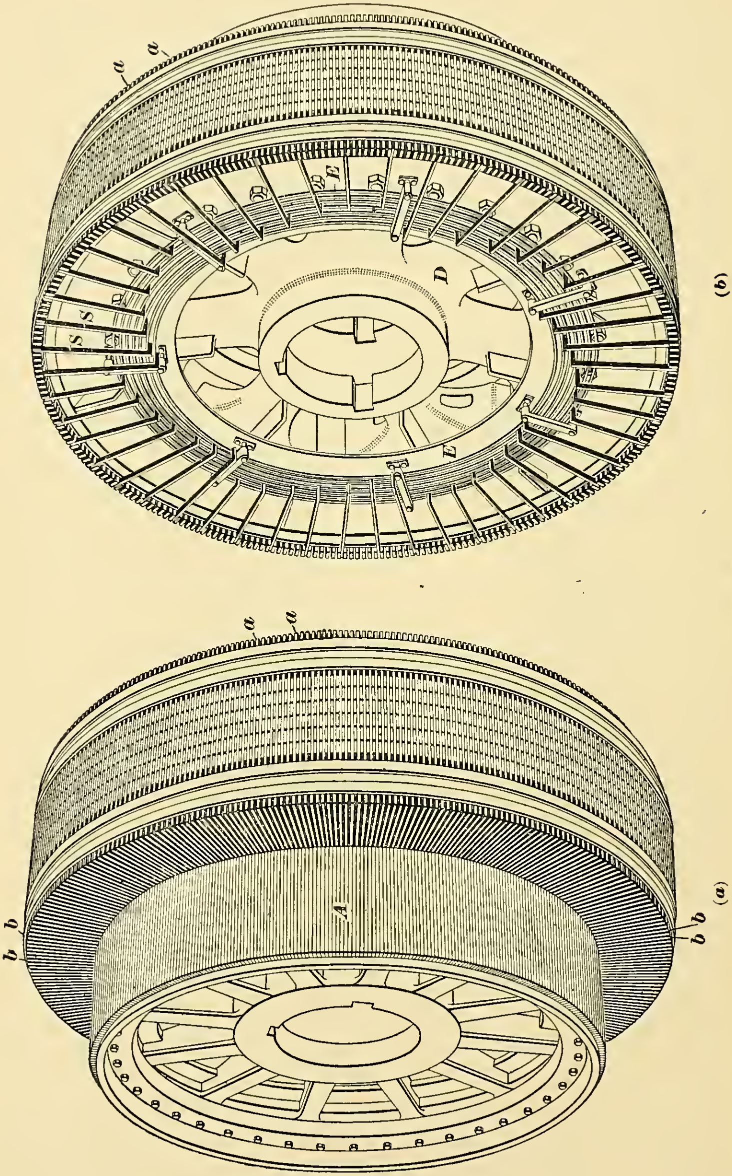


FIG. 13.

strips *b*, *b*. The laminated iron core on which the conductors are carried is mounted on the heavy spider *D*, which is keyed to the engine shaft. In these large multipolar armatures there are a number of paths in parallel; i. e., when the current enters at one side, it has the choice of several parallel paths through the armature. If the E. M. F.'s generated in these armature sections, as they might be called, were all exactly equal, the currents flowing in the different parts of the armature would also be equal. It is very difficult to have the magnetic field exactly equal all around the armature, because some of the poles may be slightly closer to the armature than are others, due to wear in the bearings or other causes. This causes the E. M. F.'s in some parts of the armature to overbalance those in other parts, giving rise to local currents that may cause the armature to heat considerably.

In order to balance the currents in the various parts of the armature, **equalizing rings,** shown at *E*, *E*, Fig. 13 (*b*), are sometimes used. These rings, to some extent, are similar to the equalizing connection used between dynamos running in parallel. They are mounted on the back of the armature and connect points in the winding that are normally at equal potential. If one section becomes overloaded, current flows through the equalizing rings to the other sections and the load is thus equalized. All armatures are not provided with these rings, and if the armature is correctly centered in the field, it works very well without them. The winding of the armature is the same in either case, the rings being simply connected by pieces *S*, *S* to the projecting ends of the bars at the back.

38. Fig. 14 shows a Westinghouse six-pole street-railway generator arranged for belt driving. The smaller units are, as a rule, belt-connected, and this is especially the case where there are no particular restrictions in regard to floor space. The dynamo shown in Fig. 14 has a substantial bearing on both sides of the pulley, so that there is none of the hang-over effect that is to be found on some generators of the belted type. It is true that a belted generator is not as efficient commercially as a direct-connected generator of the same type and output, but for units up to 300 horsepower the difference can as a rule be neglected. The amount of power lost in friction on a belted generator depends to a great extent on the judgment of the man that sets up the machine. If there is not room in the engine room to set the dynamo far enough from the engine, so that there shall be a slight sag in the tight side of the belt, even when the dynamo is running under full load, one may expect to have high bearing losses and, in extreme cases, hot boxes.

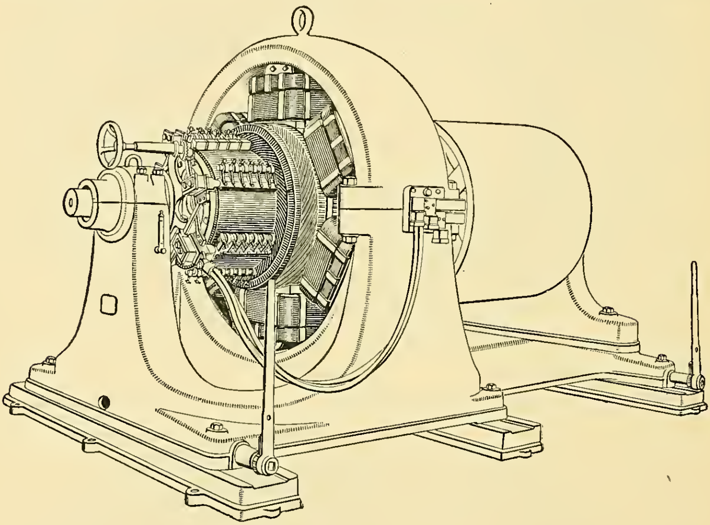


FIG. 14.

39. The **size of the generators** to be used in any plant is a subject that has aroused a great deal of discussion, some favoring a number of small machines and others a few large ones. It is not good practice to have a number of different types and sizes of dynamos in a station, because it multiplies to a great extent the number of repair parts, brushes, and general stock that must be kept on hand. For example, suppose a station to be equipped with dynamos all of the same make and size. This will mean that even if there are a number of dynamos in the station, one armature and one field, as extra parts, will do for the whole station. Whereas, if the dynamos were all of different sizes or types, one field and one armature must be kept on hand for each. Dynamos of good modern construction seldom lose a field or an armature unless struck by lightning, but they always seem much more apt to do so if the station is not prepared for such an accident. Also, different dynamos call for different brushes, bearings, brush holders, commutators, and wire. These facts are advanced as arguments against the use of a number of small dynamos to take up the required load.

On the other hand, the following points must be kept in mind: A dynamo runs at its greatest efficiency when it runs at or near full load, because, under this condition, most of the work put into it by the steam engine is given out again as useful work; but if the dynamo runs with a light load, it may be that as much work is used in overcoming the internal and frictional losses as is sent out on the line, in which hypothetical case the machine runs at an efficiency of only 50 per cent. If the dynamo is up to speed and its field is excited, but its line switch open, all the work given to the dynamo is wasted; none goes out on the line, so that the machine runs at an efficiency of zero. This goes to prove that any given dynamo or dynamos should be run at as nearly full load as possible, so that the losses may become a small percentage of the total power supplied by the steam engine. This means, in actual practice, that when the load on the station falls off, so that the single dynamo carrying it is only half loaded, it should be cut out and replaced by one of smaller capacity.

Again, for several reasons, a large dynamo at full load is more efficient than a small dynamo at full load; but a large dynamo at half load is not, as a rule, more efficient than one of half the capacity at full load. Also, one large dynamo at full load is much more efficient than a number of small dynamos whose aggregate capacity is the same as the large one; because in the large dynamo not only are the frictional and internal losses smaller proportionately than those on any one of the small dynamos, but in the case of the large dynamo these losses occur but once, whereas, in the case of a number of small machines, each machine has its own losses and their sum is much greater than the single loss on the large machines. The general conclusion to be drawn, then, is that in the actual operation of dynamos it is best to have the whole station load carried by one generator at full load, or at least to keep those generators that are in operation running as nearly at full load as possible.

40. Use of Compound-Wound Dynamos.—The fact has already been mentioned that compound-wound dynamos are used for operating street-railway systems. In the early days of electric railroading shunt dynamos were used, but they have since been displaced by the compound-wound machines. The reasons for the use of the latter are twofold. In the first place, compound-wound dynamos will operate well in parallel if they are properly installed. In the second place, they have the valuable property of holding the voltage constant or even increasing it as the load is applied; whereas, with the shunt machine, under similar conditions, the voltage will fall off unless field resistance is cut out. Compound-wound dynamos used for operating railways are the same, as regards their construction and connections, as those used for lighting or other kinds of work; hence, what has already been said in regard to compound-wound machines in general applies equally well to railway generators.

41. Overcompounding.—If a power station is equipped with ordinary shunt dynamos, the distribution of load among the several machines must be regulated either by means of shifting the brushes or by the field rheostats; but compound-wound dynamos are not supposed to require any such hand regulation. Once adjusted, under the proper conditions, they will not only share the load proportionately among themselves, but they will keep the voltage, at a specified point, up to normal value, without any further adjustment of the rheostats, because any increase in the load that would cause the terminal voltage on an ordinary shunt dynamo to drop must pass through the series coils and strengthen the field, thereby restoring the voltage to normal value. Nearly all railway generators are **overcompounded**, i. e., the voltage rises as the load increases. This increase in voltage at the machine terminals is usually from 10 to 20 per cent.; that is, if the normal voltage on an open circuit is 500 and the dynamo at full load gives a terminal voltage of 550, the machine is said to be 10 per cent. overcompounded; if the full-load terminal voltage is 600, the machine is 20 per cent. overcompounded. A compound-wound dynamo will hold the voltage constant at only one point, so that if the machine is overcompounded to hold the voltage constant at some point out on the line, the voltage in the station will move up and down; and if it is compounded to keep the station voltage constant, the voltage at points out on the line will vary.

In spite of the fact that a railway system may be supplied by a good machine heavily overcompounded, it is quite common to see the voltage on removed parts of the system vary between wide limits; in some cases the car lamps almost go out every time a car is started or the speed of a car increased. That such a state of affairs exists is in no way due to a fault in the dynamo. If the dynamo is compounded to look after a 10- or 20-per-cent. loss in the line, it cannot be expected to look after a 40- or 50-per-cent. loss due to a poor rail-return circuit, nor can it be expected to compound at some point 4 or 5 miles farther out on the line than it was originally adjusted for. As a rule, compound-wound dynamos have a shunt in multiple with their series field, as already explained. If this shunt works loose, the greater part of the current will flow through the series field and the dynamo will overcompound more than it should. On the other hand, if a series-field connection becomes loose or the shunt short-circuited, the series field will be weakened and the dynamo will fail to overcompound as much as it should. How much the dynamo will overcompound depends on the relative resistances of the series-field coils and the series-field shunt with which they are in multiple. Any change in this relation also changes the degree to which the dynamo will overcompound.

42. Connections for Compound-Wound Generator. Fig. 15 is a sketch of the connections of an ordinary four-pole railway generator. The machine indicated in Fig. 15 has four poles and four brush holders, but it has only two armature terminals, because alternate brush holders are connected together by means of a half circle copper strip. If the machine had eight or ten poles and eight or ten brush holders, it would still have only two armature terminals, because all brushes of the same polarity would be joined together.

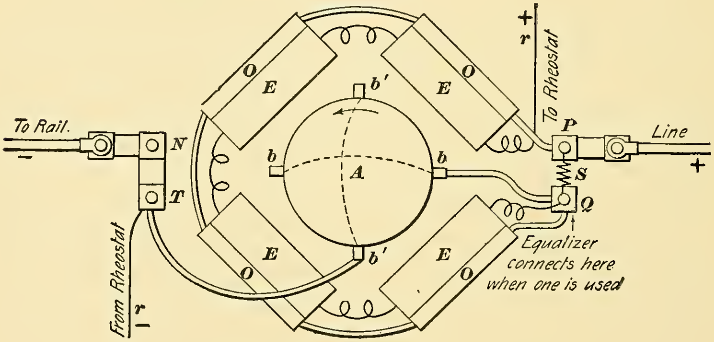


FIG. 15.

It will be noticed that each field coil is divided into two sections—a thin section next to the frame and a thick section next to the armature. One section is the fine-wire shunt field and the other section is the series field, which is usually wound with copper strip. The two sections are not only carefully insulated from the frame of the dynamo, but are insulated from each other. They are put on the spool alongside of each other, so that in case of trouble in one section, it can be taken off without disturbing the other section. Sometimes the shunt coils are placed next the yoke and the series coils next the armature, but it makes no difference, as far as the operation of the machine is concerned, in what relation they are placed.

43. In Fig. 15, *A* represents the commutator; *O*, the series field; *S*, the shunt to the series field; *E*, the shunt field, and *r*, *r* the lines leading to the rheostat for varying the strength of the shunt field. *P* and *N* are the terminals; one goes to the trolley wire and the other to the rail. The actual arrangement of the connections will of course vary somewhat with different makes of machines, but this sketch will serve to illustrate the general arrangement. One end of the fine-wire field connects to block *Q* by means of a small connecting screw, and the other end passes to the field rheostat and comes back to the negative side of the dynamo at block *T*. The cable on the right, marked "Line," leads from the positive side of the dynamo to the trolley wire; the line cable on the left comes from the rail. The current, therefore, goes out of the dynamo on the right-hand side and goes into it on the left-hand side. Coming out of the armature by way of the *b–Q* armature terminal, it splits into three parts as soon as it gets to block *Q*. One part takes the path *Q–E–E–E–E–r*+, through the field rheostat and back to the negative side of the dynamo by way of the rheostat wire *r*—, to block *T*. Another part takes the short path *Q–S–P* through the series-field shunt *S* to block *P*, while the third part reaches block *P* by way of the path *Q–O–O–O–O–P*, thus flowing through the series coils.

44. Connecting Field Coils of Compound-Wound Generators.—One very necessary point to look after in connecting the fields of any dynamo is to see that the shunt field is so connected that the machine will pick up and hold its voltage on open circuit; also, that the series and shunt fields are connected so that they will be of the same polarity and therefore help each other; i. e., so that they will both tend to magnetize the field the same way. If, in Fig. 15, the top shunt-field wire is made to exchange places with the bottom shunt-field wire—that is, if the E–Q fine wire is run to the field rheostat and the E–r+ fine wire is made to take its place at Q—the effect will be to reverse the polarity of the shunt field, and the machine will refuse to generate on open circuit, unless the direction of rotation of the armature is reversed.

45. The Series-Field Shunt. — The use of a shunt across the series field to regulate the effect of the series coils has already been mentioned, and railway generators are usually provided with such shunts. This shunt is generally made of German-silver ribbon. German silver is used because not only is its resistance high, but this resistance remains comparatively constant throughout wide variations in temperature. The strips are folded back and forth, as shown in Fig. 16, well wrapped with heavy tape, and painted with insulating paint. The shunt is also provided with terminals on the ends. The shunt should always receive its final adjustment after the dynamo is heated. A dynamo adjusted for a certain amount of compounding while it is cold will fall short of this amount after it is hot. This is due to two main causes. In the first place, the shunt field loses strength as it gets hot. When a machine is compounded properly, its voltage is adjusted to normal value on open circuit; the shunt coils supply a field to generate this voltage, which should, without further regulation, remain the same for any length of time. If the open-circuit

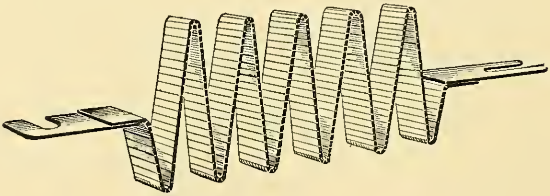


FIG. 16.

adjustment is made while the fields are cold, their resistance increases as they become heated and this cuts down the field current, thus decreasing the magnetizing power. This can be proved by adjusting the open-circuit voltage to 500 while the dynamo is cold, letting it run an hour or so on open circuit, and again trying the voltage; it will be found to be much lower. Again, when the series coils are cold, they have a certain resistance, and the shunt across the series coils is adjusted accordingly to bring the full-load voltage to the desired value. Let us assume, for example, that the German-silver shunt and the series coils with which it is in multiple have the same resistance, so that each takes the same amount of current. Now, the shunt is outside, exposed to a free circulation of air, and if it is properly proportioned, its temperature will change very little from no load to full load, and even if the temperature changes considerably, the change in resistance will be so small that it can almost be neglected. On the other hand, the series coils are buried inside the field spool, where the facilities for radiation are poor, and their resistance increases materially; the result is that the hotter the machine gets, the greater becomes the disparity in resistance between the series field and its shunt.

46. A dynamo tender should know in what position to place the field-rheostat handle bar, in order that the machine will generate normal voltage on open circuit after it has become heated. It is true that a dynamo adjusted to compound to a given degree hot will overcompound when cold, but this condition does not last long enough to do any harm. Besides, the tender should not, when the machine is cold, advance the rheostat handle bar at once to the position that will give the normal voltage when hot. The bar can be gradually worked around to that position as the fields become heated. In a great many cases, the full benefit of a dynamo's compounding property is never made use of. Especially is this so where there are several compound-wound dynamos to be run in multiple on the same load. An

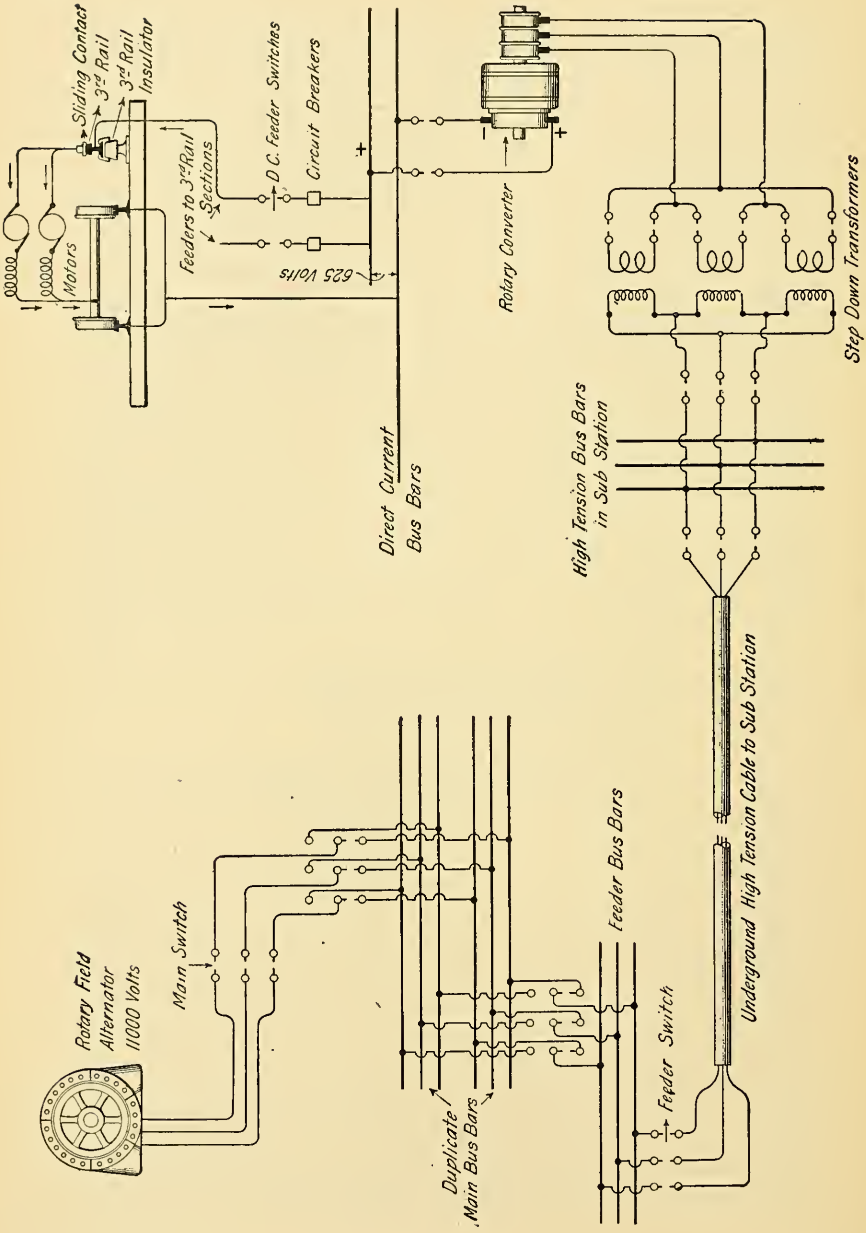

Rotary Field
Alternator
11000 Volts
Main Switch
Duplicate
Main Bus Bars
Feeder Bus Bars
Feeder Switch
Underground High Tension Cable to Sub Station
High Tension Bus Bars
in Sub Station
Step Down Transformers
Rotary Converter
+
-
Direct Current
Bus Bars
625 Volts
D.C. Feeder Switches
Circuit Breakers
Feeders to 3rd Rail
Sections
Sliding Contact
3rd Rail
3rd Rail
Insulator
Motors

FIG. 17.

attendant will look at the ammeters, see that one dynamo is taking more or less load than it should, and immediately proceed to give its rheostat bar a twist to even up the load. In a little while it will be necessary to give that same bar or some other one another twist, and so on. It is very often the case that the existing conditions are such that to make the dynamos share the load properly, this practice must be resorted to. If such conditions exist, they should be changed. The station should be compounded as a unit. After a rheostat is once adjusted to make its machine give normal voltage on open circuit when hot, it should not be necessary to disturb it afterwards.

ALTERNATING-CURRENT MACHINERY FOR RAILWAY WORK.

47. Alternators.—The use of alternating current for the operation of electric railways has already been referred to. Some very large systems are now operated by alternating current, among which may be mentioned the Metropolitan Railway and Manhattan Elevated systems in New York and the Central London Underground. Most of the large systems that spread over a wide area are now being operated by distributing the power from one main central station to a number of substations, where the alternating current is changed to direct current, which is supplied to the cars. To carry out such a scheme of transmission, two-phase or three-phase alternating current is used, the latter being the more common. The current at the main station is usually generated by large revolving field alternators, because this type admits of a high pressure being generated in the machine and avoids the use of step-up transformers at the station. Where water-power is available, the alternators are direct-connected to turbines.

48. Fig. 17 shows the general scheme of distributing current for the Manhattan Elevated Railway, New York, and will serve to illustrate the general method of distribution referred to above. Current is generated in one large central station by revolving-field, three-phase alternators direct-connected to 8,000-horsepower engines. The use of the revolving-field type of machine enables the current to be generated at 11,000 volts in the machine. It is distributed to a number of substations by means of heavily insulated lead-covered cables run in underground conduits. At the substations it is passed through stationary transformers that step down the voltage. The rotary converters change the alternating current to direct current at about 625 volts, and from the substations it is supplied to the cars by means of a third rail and the ordinary track. The systems of distribution used by the Metropolitan Railway Company, of New York, and the London Underground are almost exactly the same as this one, except that the distributing pressures are somewhat lower. In the case of the Metropolitan road the distributing pressure is 6,600 volts.

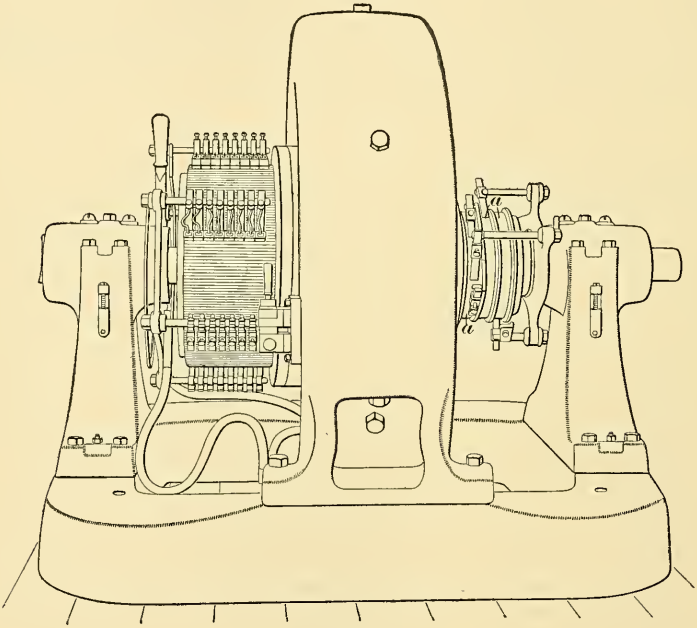


FIG. 18.

49. Rotary Converters.—As before mentioned, alternating current is used comparatively little to propel the cars themselves, but is first changed to direct current by means of rotary converters. Fig. 18 shows a three-phase rotary converter designed for railway work; it is a six-pole machine of 300 kilowatts capacity. The high-pressure alternating current from the line is first run through step-down transformers and then supplied to the rotary through the collecting rings *a*, *a*; the direct current is supplied to the cars from the commutator side. Rotary transformers are not provided with a pulley, because no outside source of mechanical power is required to drive them.

50. Double-current generators are machines that generate both alternating and direct current. In appearance they look almost exactly like a rotary converter, except, of course, that they are provided with a pulley or are direct-connected, so as to be driven from an outside source of power. Their whole output may be utilized as direct current, as alternating current, or as a combination of the two. These machines have been used to some extent in stations where a part of the power must be used close at hand and a part transmitted for a considerable distance. The part of the railway near the station is supplied from the direct-current side and the distant part is supplied through step-up transformers from the alternating-current side. These machines generate between 500 and 600 volts direct current, so that the alternating-current voltage is comparatively low and step-up transformers must be used to obtain the high pressure necessary for transmitting the power over long distances.

51. Alternating-Current Motors for Railway Work. Polyphase induction motors are in successful use on a few European electric railways, and it is not improbable that these motors will be more used in the future. Those that have been used are the same in their essential parts as the ordinary stationary induction motor, but are cased in and have about the same general appearance as ordinary direct-current motors, which are to be described later. They give a good starting effort, but take considerable current from the line in so doing. Their speed is usually controlled by having an adjustable resistance in the armature circuit. Those that have been used are of the three-phase type, and hence require three wires for their operation; the track answers for one of these, so that two trolley wires are necessary. In some installations three trolley wires have been used. Induction motors would be well suited for suburban lines where the overhead work would not be complicated and where it might be allowable to use a high pressure between the trolley and the rail. Induction motors could be wound for higher pressures than direct-current motors, because they have no commutator to give trouble. It is quite possible that they may come into use for suburban, elevated, and underground work, in which case the necessity of rotary converters would be done away with, and in some cases even step-down transformers would not be needed.

RAILWAY SWITCHBOARDS.

52. Switchboards are used for centralizing the many circuits used to distribute the power, and in this capacity are called on to hold the switches used in making the various connections and combinations, the instruments used for controlling and measuring the loads on these circuits, and the various protective devices necessary to insure that the expensive apparatus shall not be injured by abnormal conditions arising either in the station or out on the lines. In the earlier railway days it was the practice to string incoming and outgoing wires along the walls of the station and to mount the various devices, bus-bars, etc. upon the face of a wooden switchboard placed right up against a wall, in a position selected with no particular end in view of having the switchboard with its measuring and indicating devices anywhere near the engines and dynamos. The tendency of today is to spare nothing in the effort to have the switchboard well constructed and convenient in every way, and many of the boards now built are models in this respect. It has taken time, however, for this change to be brought about. Dynamos in their present state of perfection do not give nearly as much trouble as the older types, and on account of the state of perfection reached by the various protective and safety devices, no trouble can do the damage and cause the shut-downs that were once so common.

The switchboard, if properly arranged, is a great time and labor saver; it enables each dynamo and each circuit to be used as a separate unit; where occasion demands such practice, one dynamo can be thrown on to several circuits, and any or all of the dynamos can be cut out of circuit. All these combinations may be effected, if necessary, without the man that does it going near the dynamos.

53. Location of Switchboard.—It generally falls to the lot of the road engineer to decide where the board shall be placed in the station, and this is no easy matter, as so many different requirements must be reconciled. The tendency of the day in large stations is to have one man give all his time to the operation of the switchboard and do absolutely nothing else. In very large stations, where large currents are handled and large units must be used, it keeps one man busy watching the total station load and the individual dynamo loads, to see that just enough and not too many dynamos are in operation to care for the load, and that no dynamo is taking more than its share. On the smaller roads, however, it is, as a rule, the duty of one of the engineers to operate the switchboard.

Among other things, the location of the switchboard is fixed by the relative position of the dynamos and engines. The switchboard should be so placed that there will be no necessity for the engineer, in case trouble occurs at any point or in case he must get to the throttle of an engine, to go through a belt or down a flight of stairs. The life risk should be kept in mind above all other considerations. After this, perhaps, comes a consideration of the economy side of the question. If the board is very far from the dynamos, the drop in the connecting wires will be considerable, and the machines are apt to equalize badly unless the equalizing wire is run directly between the machines and not carried to the switchboard at all. When dealing with small currents, the question of drop in a large wire almost escapes notice, but when we deal with currents of several

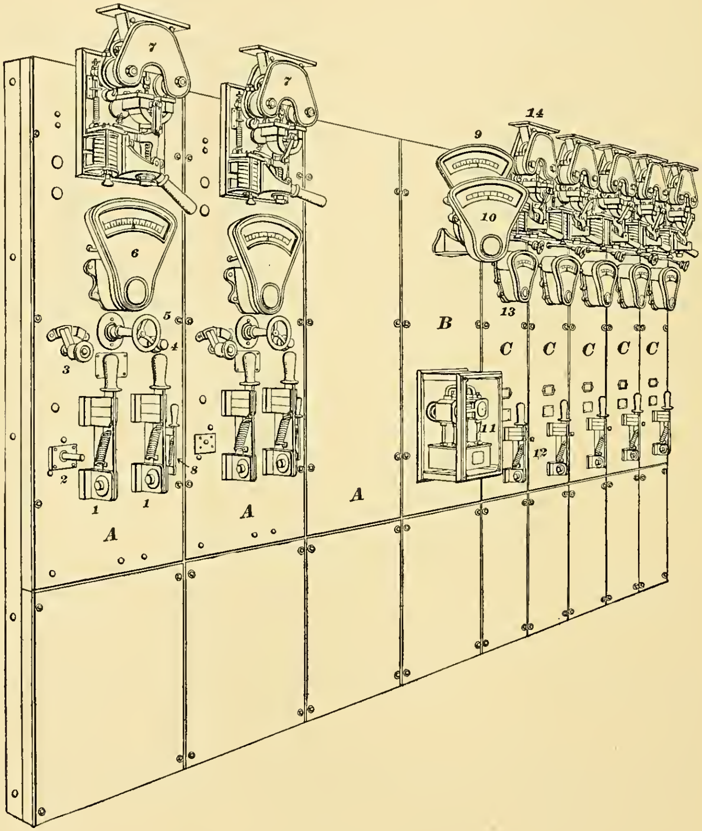


FIG. 19.

thousand amperes, such losses become an important item and care must be taken to reduce them to a minimum.

54. Materials Used for Railway Switchboards.—Railway switchboards, like all other modern boards, are made of fireproof material throughout. The board itself is usually made of slate or marble about 2 inches thick, and is bolted to vertical angle irons. The instruments are mounted on the face of the panel, and all connections between them are made on the back. The board is stood out from the wall or mounted in such a way that the back shall be easily accessible in case it is necessary to do work on any of the connections. Fig. 19 shows a typical railway switchboard for handling 500-volt direct current. This board is made of three *generator panels A*, *A*, *A*, one *total output panel B*, and five *feeder panels C*, *C*, etc. Only two of the generator panels are equipped with instruments, the third being left blank to accommodate a third machine when it is installed. Generator panels are usually about 24 to 30 inches wide and feeder panels 16 inches; the total height of the board is 90 inches.

55. Equipment of Generator Panels.—Each generator panel carries the switches and instruments necessary for the generator to which it is connected. These are as follows: *main switches 1*, *1*, *voltmeter plug 2*, *field switch 3*, *pilot-lamp receptacle 4*, *field rheostat 5* (the rheostat itself is mounted on the back of the board with the operating handle in front), *ammeter 6*, and *circuit-breaker 7*. The small switch *8* is used for controlling any station lights or motors that may be operated from the machine.

56. Equipment of Total-Output Panel.—This panel is not always provided, but it is generally installed in the best plants. It generally carries the *voltmeter 9* and a *total-output ammeter 10*, which is connected so that it indicates the total combined current delivered by all the generators. This panel is also equipped with a *recording wattmeter 11*, which measures the total number of watt-hours delivered by the station, so that an accurate account may be kept of just what work the station is doing.

57. Equipment of Feeder Panels.—The feeder panels are supplied with the equipment necessary for the control and measurement of the current on the different feeders going out from the station. Each panel is equipped with a *feeder switch 12*, a *feeder ammeter 13*, and a *circuit-breaker 14*. On some boards the feeder panels are not equipped with ammeters.

58. General Remarks.—The advantages of the panel type of construction are that it groups the apparatus belonging to each individual part of the plant by itself; also, it allows the board to be extended easily in case the plant is enlarged either by adding more feeders or more generating apparatus. As a rule, only one voltmeter is necessary, because by means of the plug *2* the instrument may be connected to any machine in case a reading is desired. Some boards, however, have two voltmeters, one of which is permanently connected across the bus-bars and the other arranged so that it may be connected to any machine. This is a convenient arrangement where a machine is being thrown in multiple on the bus-bars, but it is not essential that the board should be equipped in this way. The voltmeter is often mounted on a swinging bracket, as in Fig. 19, so that it may be readily seen by the operator. In case a total-output panel is not provided, the voltmeter is often mounted on a swinging arm at one end of the board. In addition to the apparatus shown in Fig. 19, each generator panel, and in some cases the feeder panels also, is equipped with lightning arresters mounted behind the board.

RAILWAY SWITCHBOARD APPLIANCES.

59. Main Switches.—Before considering the connections necessary for a railway switchboard, we will take up the various appliances used on the board. The *main* *switches* shown at *1*, *1* are, of course, intended to disconnect their generator from the bus-bars. These switches should be of substantial construction, as they are called on to carry a heavy current. They are usually made so as to give a quick break and thus prevent arcing. In general, however, the main switches are not used to open the circuit when the machine is carrying a load. If it is necessary to do this, the circuit-breaker should be used, because it is constructed so that it will break the circuit without any injurious arcing. Single-pole switches are generally used on railway boards. In Fig. 19, two main switches are shown on each generator panel, though it is quite common to find three switches. If the equalizer wire is run to the switchboard, then three switches are used, but if it is run between the machines, as is done in the more recent installations, only two switches are necessary on the board, and the equalizer switch is mounted on a stand near its dynamo.

60. Voltmeter Plugs and Switches.—These are used to enable the voltmeter to be connected to any one of the generators. For railway boards, a plugging arrangement is generally preferred to a switch, as it is less complicated and more substantial. The plug is arranged so that when it is inserted as shown at *2* on the first panel, Fig. 19, it connects the voltmeter *9* across the dynamo connected to the first panel. The way in which this is carried out will be apparent when we come to take up the switchboard connections.

61. Field Switch.—The field switch is used to open the shunt-field circuit of the generator; it is, therefore, of comparatively small current-carrying capacity. The shunt-field winding of a railway generator consists of a great many turns of wire, and it must not be forgotten that if the shunt-field circuit is suddenly broken, an exceedingly high E. M. F. will be induced in the winding, due to the sudden decrease in the magnetization threading through the field coils. The field switch must, therefore, be arranged to take up any discharge from the field, otherwise the high induced voltage may puncture the insulation on the field spools.

Fig. 20 shows the arrangement of the field switch and pilot lamp used on the board in Fig. 19. The switch S has two contact segments a, a', and the tongue t is wide enough to bridge over the gap between them. The switch is shown in the position that it occupies when the generator is in operation. The current then passes through the field rheostat r and the switch S as indicated by the arrowheads. When the switch is moved to the position indicated by the dotted line, connection between the field and the negative side of the armature is broken, but before the break takes place, tongue t comes into contact with a', so that the shunt field, the rheostat r, discharge resistance r', and pilot lamp l all form a closed circuit. The shunt field is thus able to discharge through this closed circuit, and danger of puncturing the insulation is avoided. When the machine is being started, the tongue t is placed in its mid-position, so that current can flow through r' and l as well as through the shunt field and rheostat r. As the machine builds up, the pilot lamp becomes brighter, thus giving the attendant an indication as to whether the machine is "picking up" properly or not. After the machine has come up to voltage, the switch is moved to the position shown in the figure and the pilot lamp is cut out. On some boards, five or six lamps in series are used in place of the resistance r' and the single lamp l. The pilot lamp l is inserted in the receptacle *4*, shown in Fig. 19.

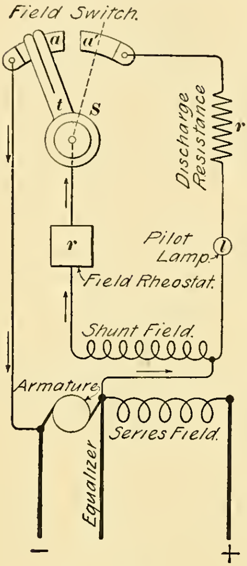


FIG. 20.

62. Field Rheostats.—Field rheostats, or resistance boxes, are used in connection with all railway generators, and are connected in series with the shunt-field winding, so that the field current, and hence the voltage of the generator, may be adjusted. The field resistance is not intended to be used for regulating the voltage to suit the variations in load, because the compound winding is supposed to take care of that. It is used to adjust the voltage when the machine is first started, and it is also necessary to cut out some of it as the field coils warm up.

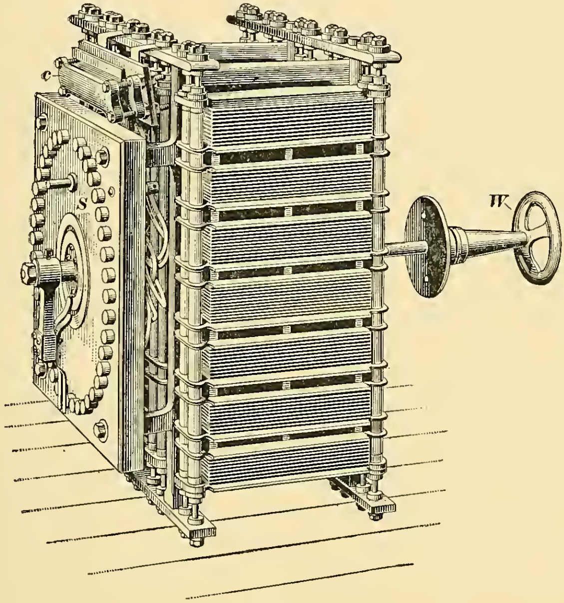


FIG. 21.

Field rheostats used on railway boards are made in a great variety of designs, but in all cases they consist of a resistance split up into a large number of sections that are connected to a multipoint switch, so that any amount of resistance may be cut in or out. In some styles the resistance is made up of German-silver or tinned-iron wire coiled into spirals and mounted in a well-ventilated iron box. In others, the wire is formed into zigzag shape and mounted in enamel on the back of cast-iron plates. In all cases, rheostats should be constructed so that they will be perfectly fireproof and at the same time allow easy radiation of the heat generated in them. If the latter point is not considered, burn-outs are apt to result. In some rheostats the resistance is in the form of cast-iron grids of zigzag form. This makes a substantial resistance that is well ventilated and is especially suited to rheostats of large capacity.

63. When rheostats are of comparatively small size, they are mounted on the back of the switchboard and operated from the front. Fig. 21 shows a type used by the General Electric Company on railway boards and arranged for mounting on the back. The switch is shown at *S* and is operated by the wheel *W* on the front of the board. In this particular rheostat, the resistance wire is wound on sheet-asbestos cylinders, which are afterwards flattened and clamped between pieces of sheet iron covered with asbestos. The wire is thus held firmly in place, and the pieces of iron nearest the wire serve to radiate the heat. To allow the voltage to be regulated by small steps, it is necessary to have a considerable number of points on the rheostat switch. Another method of accomplishing the same result is to have a small resistance connected to the switch arm, so that it will be put in multiple with each step as the arm is moved around. This scheme is used in the rheostat shown in Fig. 21, and will be understood by referring to Fig. 22. The regular rheostat contacts are arranged as usual and are shown at *1*, *2*, *3*, etc. Instead, however, of using a simple contact arm, the arm is provided with two contact tips *a*, *a'*, insulated from each other, and which press on the contact rings *b*, *b*; *c* is a small so-called multiplying resistance (see also *c*, Fig. 21), which is

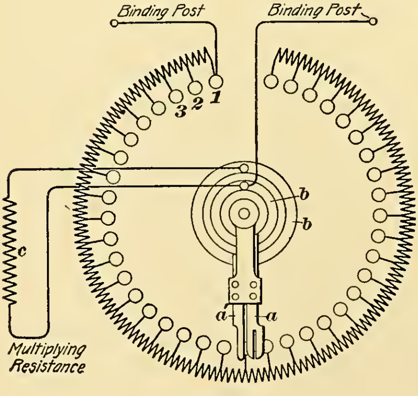


FIG. 22.

approximately equal to one of the resistance sections on the rheostat. By tracing out the current, it will be seen that *c* is placed in parallel with the step on which the arm rests, and it has the effect of practically halving the resistance of each step as the arm is moved around ; it, therefore, gives as fine an adjustment as though the rheostat were provided with a single arm and twice the number of steps.

When very large generators are used, the rheostat is generally mounted separately from the switchboard. In some cases, the switch is placed on the back of the board and is connected by wires running to the resistance, which may be mounted in any convenient location. In other cases, the rheostat and switch are both mounted away from the board and are controlled by a shaft fitted with bevel gears, or by a chain-and-sprocket arrangement. This arrangement is preferable to running wires from a rheostat switch on the board to the rheostat itself.

64. Ammeters.—Each generator should be provided with an ammeter that will indicate its current output. It is also advisable to have an ammeter in each feeder. The load on a railway generator fluctuates rapidly, and it is essential that the ammeters should be "dead-beat"; i. e., the hand should not swing back and forth, but should move to its place whenever there is a change in the current and it should stay there until another change takes place. The instrument should also be constructed so that it will require but a small amount of energy to operate it. This may seem a rather unimportant point, but where a station has a large number of instruments that are in circuit all the time, the amount of energy used in them in the course of a year may be considerable.

Weston ammeters are very largely used for railway boards. They are accurate, consume but little energy, and are dead-beat. The switchboard type used for railway work is exactly similar in principle to the portable type, but much larger. The main ammeters and voltmeters are provided with dials that are illuminated from the rear, so that they may be easily read. Feeder ammeters are not usually provided with illuminated dials.

65. Voltmeters.—At least one voltmeter is necessary on every railway switchboard, and it should be arranged so that it may be connected to any machine or to the bus-bars. The voltmeter is, of course, connected across the circuit, and it should therefore have a very high resistance, or else it will take considerable current. Voltmeters and ammeters are generally the same in appearance and the operating parts are the same, but the voltmeter has a very high resistance compared with that of the ammeter.

66. Westinghouse Railway Ammeters and Voltmeters.—On the earlier types of Westinghouse switchboards, ammeters and voltmeters of the plunger type were used. The current was led through a vertical coil or solenoid that was arranged so as to pull down an iron core hung from one side of a balance arm to which the pointer was attached. On their later boards, the Westinghouse Company use a round-style instrument, in which the current flowing in the coil acts on an iron vane placed within it, instead of on a plunger.

67. Thomson Astatic Ammeters and Voltmeters.—These instruments, invented by Professor Elihu Thomson, are used by the General Electric Company. The board shown in Fig. 19 is equipped with instruments of this type. In the Thomson astatic meters, electromagnets are used to set up the magnetic field instead of permanent magnets, as in the Weston instruments. Also, the moving coils are mounted on an aluminum disk instead of being made in rectangular shape. The retarding force acting on the armature is not supplied by spiral springs, but is provided for by the attraction of the field magnets for small iron vanes placed on the moving member. If, for any reason, the electromagnets become weaker, the force acting on the movable coils, for a given current flowing through them, also becomes weaker, but the retarding force decreases at the same time, so that the reading of the instrument is not affected. A Thomson astatic ammeter, as used on a generator panel, has six wires running to it; two of these run to the ammeter shunt, the same as for a Weston instrument; two others run to the bus-bars, so as to supply the field electromagnets with exciting current. These magnets are provided with a high-resistance winding, so that they may be connected directly across the line. The third pair is used to supply current to the lamps used for illuminating the dial. The ammeters used on the feeder panels do not have illuminated dials, hence these last two wires are not required.

CIRCUIT-BREAKERS.

68. On the first railway boards that were brought out, fuses were used to protect the machines from overloads, but it was soon found that while these might be fairly well suited to lighting or other work where the machines were not subject to violent overloads, they were not reliable for railway work, and, moreover, the renewing of blown fuses was a nuisance. Fuses have, therefore, been replaced by automatic circuit-breakers, of which there are several different makes. Those that have been most widely used for this service are the General Electric, the Westinghouse, and the Cutter, or I. T. E., as it is sometimes called.

The circuit-breaker, as this name is now accepted, is automatic in action and is designed to open or break the main working circuit whenever, for any reason, the current reaches a value that is not safe for the dynamos to carry. It is not a difficult matter to get up a device that will break the current at a set value for the first few times that it is operated, but it took years of study and observation in actual practice to perfect a device that would not burn and blister itself into a worthless condition in a short while when used continuously. The circuit-breaker, to be effective, must be able to break heavy currents without damage from the burning effect and this means that the arc must be almost instantly extinguished as soon as the breaker opens.

69. General Electric Type M K Circuit-Breaker.—This is a type of breaker that has been very extensively used in railway work. In it the arc is extinguished by breaking the circuit in a magnetic field. It is a well-known fact that a wire carrying a current in a magnetic field tends to move across the field, this, in fact, being the principle of operation of the electric motor. An arc formed by the current between two terminals acts exactly like a wire carrying a current; hence, if the arc is made to take place in a magnetic field, it will be forced across the field and stretched out so that it is broken. This action is almost instantaneous, and if the magnetic field is fairly strong, the arc is blown out almost as soon as it is formed. This magnetic blow-out method of suppressing arcs is largely used in car controllers, lightning arresters, and other devices.

70. Fig. 23 shows the General Electric Company's M K breaker, which is the kind also shown on the board, Fig. 19. This type has been selected for illustration on account of its ready adaptability to almost any class of service and on account of its wide range of adjustment. M K breakers can be had of any capacity from 150 to 8,000 amperes, and are therefore equally suited to feeder or to individual generator duties. In Fig. 23, *B* is a heavy tripping coil of copper, through which passes the main current that operates the breaker. The main current enters the coil through the rear connecting post *A*; from the coil it passes to a connection on the back of the heavy copper contact block *C*. When the breaker is closed ready for service, as shown in the figure, the main current passes from *C* to the curved copper bridge *D D* and out to the line again through the heavy block *E*, which has a terminal like *A* in the rear. When the breaker is closed, the hinged iron armature *F* is held up by a spring *G*, the tension of which depends on the adjustment of a thumbscrew *J*. Attached to plate *F* is a trigger *H*, which has on the under side of its end a shoulder against which a projection on the main handle yoke *K* bears. To set the breaker, the main handle *L* is pulled down hard; this forces *D D* up against blocks *C* and *E*, and also causes the projection on *K* to engage trigger *H*, which holds the circuit-breaking parts in place. In setting the switch, spring *M* is extended. Now, suppose the current to go above the value for which the breaker is set to operate.

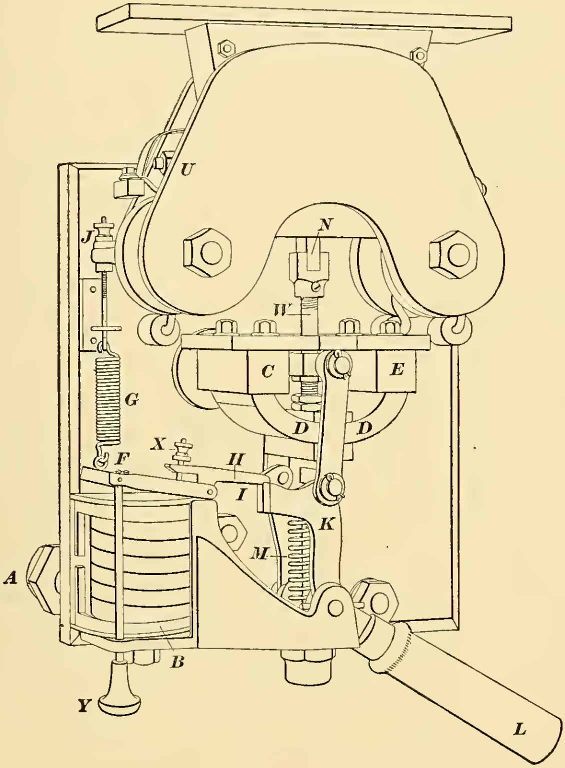


FIG. 23.

The solenoid *B* draws down its armature plate *F*, and with it the trigger *H*, which liberates the switch yoke and allows the strong spring *M* to pull down *D D*, and hence open the circuit at *C* and *E*. It can thus be seen that this part of the device is a circuit-breaker within itself, but the arrangement as it stands would provide no means of suppressing the arc, and the blocks *C* and *E* and the bridge *D D* would burn badly. Fig. 24 is a diagrammatic sketch of the path of the main current through the breaker. The tripping coil *B*, the blocks *C* and *E*, and the bridge *D D* are all in series, forming part of the main circuit. Let us now see how the arc is cared for. By taking the name plate off the breaker, a chamber is exposed that contains an arrangement similar to that shown in

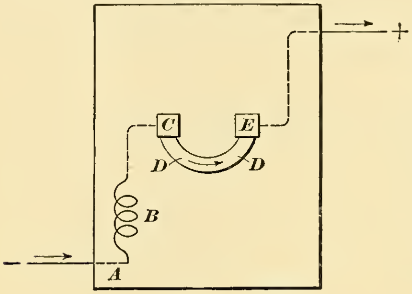


FIG. 24.

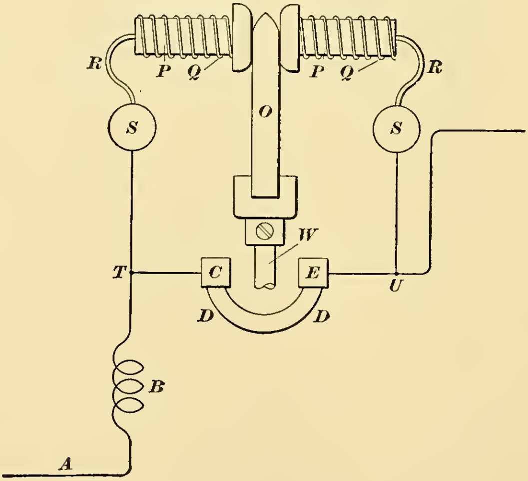


FIG. 25.

Fig. 25 and constituting what is called the *secondary break;* the break between *C* and *E* and the bridge is the primary break. *P*, *P* are two copper plunge contacts that are impelled towards each other by springs *Q*, *Q*, but which do not touch each other even if *O* is pulled out from between them; the switch tongue *O* is carried on a rod that is actuated by the movement of the main handle *L*, which also works the main bridge contact *D D*, but there is lost motion between contact *O* and contact *D D*, with the result that when the breaker works, *D D* leaves *C*, *E* before *O* leaves *P*, *P*. *S* and *S* are two coils that provide a powerful magnetic field across the place where the tongue *O* leaves the contacts *P*, *P*. By means of strips *R*, *R* each of the coils is connected to the *P* contact nearest to it. It can be seen, then, that the two coils *S*, *S*, the two contacts *P*, *P*, and the contact *O* are in series. When the breaker is set, *O* connects *P* and *P*, and *D D* connects *C* and *E*, so that when current entering the breaker at *A* gets to point *T*, it has a choice of two paths by means of which to reach point *U*; one path is straight across *T–C–D D–E–U*; and the other path is *T–S–R–P–O–P–R–S–U*. The primary and secondary paths, then, are in multiple. When the breaker is set, however, the resistance of the secondary path is comparatively so high that it takes little or no current. As soon as an overload causes the tripping coil *B* to trip the trigger *H*, *D D* leaves *C*, *E* at once, with very little arcing, because the current has still a good path through the secondary circuit. The same movement that pulls bridge *D D* from blocks *C*, *E* withdraws tongue *O* from between contacts *P*, *P*, a little later, however, so that although the circuit is open at *D D*, there is, nevertheless, an arc holding across *P*, *P*. The strong magnetic field across *P*, *P*, however, soon forces this arc upwards and breaks it, all smoke and gases being driven out through a draft hole in the top of the chamber that encloses the device. Frequent actions will, in course of time, deposit on the walls of this chamber a film of carbon, which, if not cleaned off, will cause a short circuit and will blow up the breaker. Contact blocks *P*, *P* have nuts by means of which the air gap between them can be adjusted. One of these nuts can be seen at *U*, Fig. 23. The stem *W*, Figs. 23 and 25, also has adjusting nuts, by means of which the amount of lost motion between *O* and *D D*, and hence the interval of time elapsing between the break at *P*, *P* and that at *D D*, can be regulated. As wear takes place in any of the connecting parts or as the contacts become burned, some of the lost motion must be taken up in order to preserve the right relationship between the time of breaking in the primary and secondary circuits. Contact bridge *D D* is made up of layers of leaf spring copper, so that it has more or less give to it. The result is that when the breaker is set, the surfaces of the bridge are forced apart a little, thus giving a certain amount of wipe instead of a plain butt contact. It is evident that the stronger the pull exerted on plate *F* by spring *G*, the more force must coil *B*, exercise on it, and the greater current must there be in it to draw down the plate and to trip the trigger *H*. The tension on the spring can be regulated by means of the nut seen at *J*. Also, the amount of engagement between trigger *H* and the projection on the yoke *K* can be regulated by means of the thumbscrew seen at *X*, Fig. 23. The pull *Y* is a device used to trip the breaker by hand, whether it has any current going through it or not, and is very convenient when adjusting the time interval between the primary and secondary breaks. All the contacts on the breaker should be examined from time to time, and if any rough projections are present, they should be dressed down with a file.

71. Westinghouse Circuit-Breaker. — Fig. 26 shows the Westinghouse circuit-breaker, of which large numbers are in use, and which have given very good service. No magnetic blow-out is used, but the arc is taken care of by making the break take place at auxiliary carbon contacts, where the burning does no harm, since these contacts can be renewed at small expense. In Fig. 26, *a*, *b* are the main contacts, which are connected by the crosspiece *c* when the breaker is set. The current enters at *a*, flows across *c* to *b*, thence through the tripping coil *d* and out at *e*. Coil *d* has an iron core that pulls up an armature whenever the current exceeds that for which the breaker is set. This armature is weighted with an adjustable weight *w*, by means of which the tripping point may be adjusted. The auxiliary carbon contacts are in the form of plates *m*, *m* attached to the fixed contacts *a*, *b* and carbon wipers *n*, *n* attached to the breaker arm. The arm is pushed in against the action of a spring and is held in place by a catch. When the catch is released, by the current becoming excessive, the arm flies out. Contacts between *c* and *a*, *b* break first, and the current momentarily flows through the carbon contacts. When the wipers leave the carbon plates the break takes place, so that the burning action occurs on the carbon.

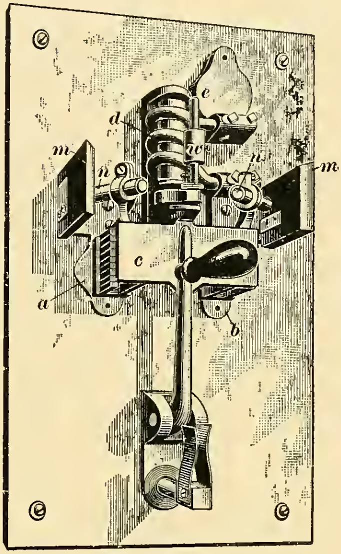


FIG. 26.

72. The Cutter Circuit-Breakers (I. T. E. Breakers). These circuit-breakers are somewhat similar in appearance and action to the Westinghouse breakers. The arcing is taken care of by using auxiliary carbon breaks, but the arrangement of the tripping device is different. In these breakers, the tripping coil or solenoid sucks up an iron core when the current becomes excessive. This core is mounted loosely in the solenoid and is not attached to the trigger, but operates the latter by striking it a blow when it is drawn up. One advantage of this breaker is that there is very little danger of the tripping device sticking and failing to work.

COST OF POWER FOR ELECTRIC RAILWAYS.

Output Measured by Wattmeter in Each Case.

Station.	Month.	Monthly Output. Kilowatt-Hours.	Cost of Electrical Output per Kilowatt-Hour. Cents.						Gals. Cylinder Oil per 10,000 K. W. H.	Gals. Lubricating Oil per 10,000 K. W. H.	Lb. Water per Lb. Coal.	Lb. Fuel per K. W. H.	Price of Fuel per Ton of 2,000 Lb.	Kind of Fuel.
			Fuel.	Labor.	Supplies, Oil, Waste, Etc.	Water.	Repairs.	Total.						
1	Jan.	2,455,060	.322	.111	.029	.029	.044	.535	2.62	.848	10.83	2.45	$2.63	Bituminous
1	Feb.	2,511,280	.334	.114	.036	.027	.025	.536	2.64	.829	10.05	2.54	2.63	"
1	Mar.	2,097,160	.337	.123	.037	.030	.040	.567	2.84	.987	11.21	2.55	2.64	"
1	Apr.	2,158,660	.344	.129	.039	.032	.043	.587	2.98	.722	11.37	2.61	2.64	"
5	Jan.	2,445,161	.408	.110	.013	.011	.016	.558	2.18	1.31	5.51	4.10	1.99	"
5	Feb.	2,512,125	.389	.116	.014	.008	.011	.538	2.50	1.08	5.32	3.89	2.00	"
5	Mar.	2,352,698	.405	.126	.018	.011	.016	.576	2.52	1.70	5.15	4.33	1.87	"
5	Apr.	1,887,029	.347	.149	.020	.011	.036	.563	3.91	1.14	5.22	4.22	1.65	"
6	Nov.	827,008	.712	.198	.033	....	.067	1.010	....	.....	.....	2.35	.943*	Oil
6	Dec.	810,728	.709	.198	.024	....	.070	1.001	....	.....	.....	2.36	.937*	"
6	Jan.	643,482	.680	.251	.038	....	.185	1.154	....	.....	.....	2.24	.945*	"
6	Feb.	494,000	.655	.282	.037	....	.181	1.155	....	.....	.....	2.25	.905*	"
6	Mar.	562,574	.761	.266	.031	....	.059	1.117	....	.....	.....	2.42	.976*	"
6	Apr.	616,634	.628	.236	.030	....	.095	.989	....	.....	.....	2.31	.843*	"

* Price of oil per barrel.

COST OF POWER.

73. The cost of generating power in electric-railway plants varies greatly, as one would naturally expect. The actual cost per kilowatt-hour at the switchboard includes so many items that are subject to such wide variation that it is difficult to give even approximate figures relating to cost. In fact in even the same station the cost will be higher during some months than others. The accompanying table, from the Street Railway Review, gives figures relating to the cost of generating power in some stations of considerable size. It should be noted that the total cost covers only the items of fuel, labor, supplies, water, and repairs. It does not allow for interest on the investment or depreciation of the plant. In a large number of plants the total cost, including interest, etc., will lie between 1 and 2 cents per kilowatt-hour, and in some of the largest plants it may be somewhat below 1 cent per kilowatt-hour.

74. The amount of power required to operate each car also varies greatly on different roads, and the cost per car mile is consequently subject to wide fluctuations. For the total operating expenses, including repairs of all kinds, office expenses, cost of labor, etc., per car mile is between 10 and 15 cents on a number of roads. The costs in individual cases might, however, vary widely from the above. The following shows the power consumption for a road operating about 400 cars, most of which were of the large double-truck type, and hence took a comparatively large current.

Average amperes used per car	75
Voltage	500
Kilowatts output per car	37.5
Cost of power per kilowatt-hour at power house	$.02
Cost of power per hour per car	$.75

ELECTRIC RAILWAYS.

(PART 2.)

RAILWAY SWITCHBOARD APPLIANCES.

1. The Recording Wattmeter.—The recording wattmeter is used to measure the total amount of energy delivered from the station. The power, or the rate at which work is done by the generators, is found by multiplying the current by the E. M. F. This gives the watts delivered at the instant at which the readings are taken. The watts multiplied by the number of hours during which they are delivered give the total work done in watt-hours. Since 1 kilowatt = 1,000 watts, the watt-hours divided by 1,000 will give the kilowatt-hours delivered, and, also, since 1 horsepower = 746 watts, the watt-hours divided by 746 will give the horsepower-hours delivered by the station. It would be an easy matter to obtain the output in horsepower-hours or kilowatt-hours for any station if the load remained constant, because all that would then be necessary would be to multiply the ammeter and voltmeter readings together and then multiply the product so obtained by the number of hours the station is in operation. This would give the total watt-hours, which divided by 746 would give the horsepower-hours. This method is, however, seldom practicable, especially in railway stations. If the load is a variable one, it is necessary to take readings at frequent intervals throughout the time during which the amount of energy absorbed is sought; then, adding the voltmeter readings together and dividing by the number of readings gives the average voltage during the time, and adding the current readings together and dividing by the number of readings gives the average current during the time under test. These two average values for the current and for the voltage, multiplied together, give the average watts, and this multiplied by the number of hours gives the watt-hours output. Where, however, the variations in load are very violent and sudden, the energy consumption for any given period of time obtained in this way is not always to be relied on, so it is necessary to use an instrument that will average up the energy delivered to the lines, and for this purpose a recording wattmeter is used on the switchboard in the best equipped stations. The Thomson meter is generally used for this purpose. The instrument used on railway switchboards is the same in principle as that previously described, though, of course, the design is considerably modified to suit it to the heavy currents that it has to handle.

2. A Thomson recording wattmeter as designed for switchboard work is shown in Fig. 1. The series coils of the ordinary meter are here replaced by the heavy copper bar *a*, through which the whole current output of the station passes, connection being made on the back of the board to the lugs *b*, *b*. Above and below this bar are the two small armatures *c*, *c*, which are connected in series with a resistance across the line, so that the current in them is proportional to the voltage. Current is led into the armatures through a small silver commutator *d*, as in the ordinary recording meter, and the reading is registered on a dial *e* in the usual way. The damping magnets used to control the speed are contained in the case *f*. The main current flowing through the crosspiece *a* sets up a field surrounding it, and this field acts on the two armatures *c*, *c*. The current in these instruments is so large that a sufficiently strong magnetic field is produced by passing the current through what is practically a portion of one turn only, whereas in the small meters several turns are required. The reading (watt-hours) is obtained in the same way as for the ordinary style of meter, and by keeping a record of the readings, the output of the station for any given interval of time may be readily obtained. This instrument is constructed so that outside magnetic fields have little or no influence on it. On some of the older styles of meters, the magnetic field surrounding the heavy conductors on the back of the board affected the meter. In this meter any stray field affects both the armatures *c*, *c*, which are so connected that an outside field tends to turn them in opposite directions, and the disturbing effect is thus neutralized. The field set up by the instrument itself is in opposite directions on the upper and lower sides of *a*, so that these two fields propel the armatures in the same direction.

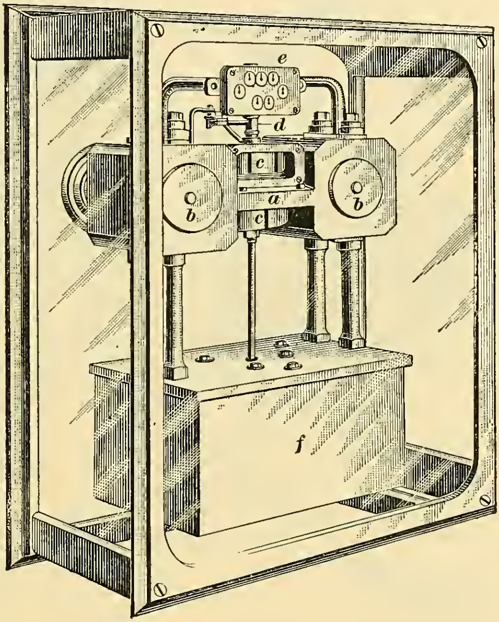


FIG. 1.

3. Car Wattmeter.—Recording wattmeters are also made in portable form for use in connection with railway work. They are very useful for making tests on the power consumption of cars. Fig. 2 shows a Thomson recording wattmeter as adapted for use on street cars. It is made so that it can stand considerable jarring without injury. It differs from the stationary types of Thomson meters in that an iron core *A* is used in the field. This gives a much stronger field than where no iron is used, thus giving a larger twisting action on the armature, so that jarring is not so liable to interfere with the accuracy of the meter. *B*, *B* are the damping magnets used to control the speed and *C* is the armature. The current coils *D*, *D* are connected between the trolley and the motors so that the current used by the car passes through them. The armature *C*, in series with its resistance, is connected across the

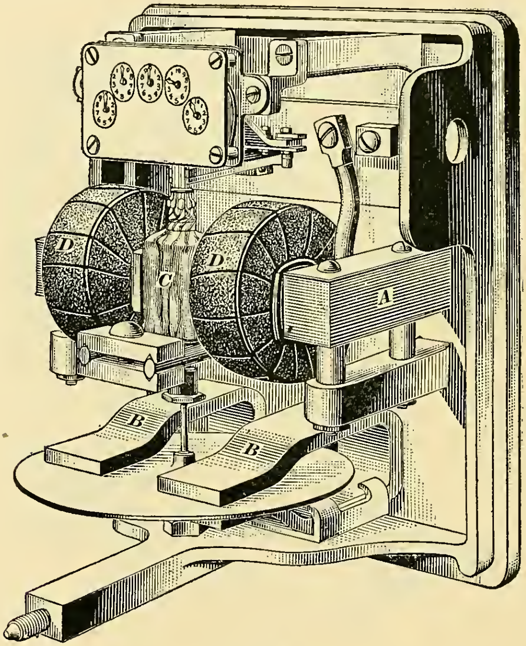


Fig. 2.

line between the trolley and ground so that the current in it will be proportional to the voltage supplied to the car. The ordinary style of stationary wattmeter is not suitable for car testing, as the shocks and jars would soon knock it out of adjustment.

4. Bus-Bars. — Railway switchboards are always provided with at least two bus-bars, and in case the equalizer connections are run to the board, an additional bar is necessary. One of the bus-bars (the positive) is run across to the feeder panels and there connected to the various feeders through the necessary circuit-breakers. The positive leads from all the dynamos are connected, through the main switches, to this bar. The negative bus-bar is usually much shorter than the positive, and is connected to the cables running to the rails or other ground-return connections. In many cases the negative bus-bar is not as large as the positive, because connection is made to ground between the panels, and hence the bar does not have to carry the combined current from all the machines. The positive bar, on the other hand, has to carry all the current across to the feeder panels. The bus-bars are generally of flat copper bar and are supported a few inches from the back of the board by means of heavy brass castings, which also serve to carry the current into them. Fig. 3 shows one of the common methods of mounting the bars. Too much stress cannot be laid on the fact that bus-bars should have ample cross-section. It is very poor economy to install small bus-bars on any board. If the loss due to the resistance of the bus-bars were to be considered for a few hours or days only, it would be small enough to neglect, but when it is remembered that this loss is taking place year in and year out, it is no small matter. The cost of the power wasted in a small pair of bars will more than offset any slight saving in first cost that may be effected by the comparatively small weight of copper.

From 1,000 to 1,200 amperes per square inch of cross-section is a safe allowance. Bolted connections between bars will, if carefully made, carry from 180 to 200 amperes per square inch of contact surface. If, for example, a bus-bar has to carry 6,000 amperes, its cross-section should be at least $\frac{6000}{1200} = 5$ square inches. The bar may be made of any dimensions that will give a cross-section of 5 square inches; generally, however, the bars are of flat, rectangular cross-section. In this case, for example, 5 in. × 1 in. would answer. When very large bars are needed, they are usually made of a number of comparatively thin bars with air spaces between. In any event, the dimensions should be so selected that connections may be made conveniently and give the required contact at the joints without lapping the bars too much. In the above case, a joint in the bar should have at least $\frac{6000}{200} = 30$ square inches surface, and the 5-inch bar should be lapped 6 inches. Great care should be taken to see that all joints on bus-bars or between the bus-bars and switches are well made and bolted tight. The current to be handled is large, and a poor contact, having what would, under ordinary circumstances, be called a very low resistance, may give rise to considerable local heating. If an equalizer bar is used, it is very essential that all its connections should be well made. A slight resistance at this point may interfere with the

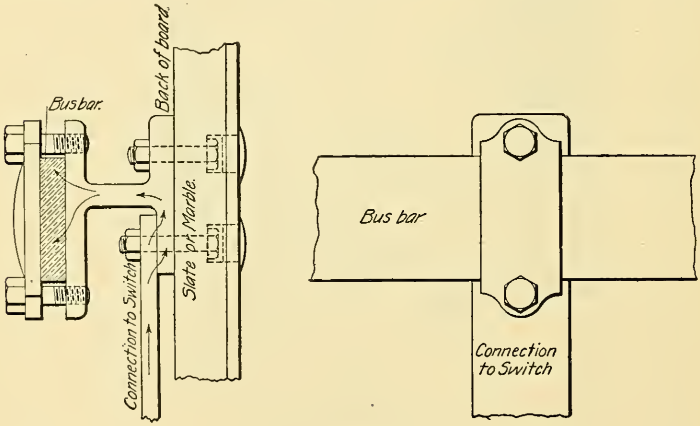


FIG. 3.

proper working of the machines in multiple. If at any time the machines fail to work together as they should, examine all the connections through which the equalizing current has to flow, to see that none of them has become loose.

5. Lightning Arresters.—A lightning arrester designed for use on a railway circuit has to operate under especially severe conditions, because one side of the system is grounded, and whenever a discharge passes through the arrester a short circuit results; besides, the pressure on railway systems (500 to 600 volts) is comparatively high. A great many different types of air-gap arresters have been used and are in all cases provided with some device to extinguish the arc following the discharge. In the General Electric Company's arresters the arc is extinguished by a magnetic blow-out arrangement, very similar to that used on their circuit-breakers. In the Garton arresters the arc is formed in a confined space and drawn out until it is broken, the action being almost instantaneous. In one type of Westinghouse arrester the discharge leaps across charred grooves in a confined space between two lignum-vitæ blocks and is practically smothered out. All these arresters are used for railway work. Of course, no matter what type is used, it is liable to fail at times, and arresters should be used liberally out on the lines instead of depending altogether on the station arresters.

6. Westinghouse Tank Arrester.—Fig. 4 (*a*) and (*b*) shows a style of arrester that has been used extensively for railway stations. This device, which is known as the **tank arrester,** differs materially from the ordinary air-gap arresters. The object and action of the tank arrester is to ground through a water resistance that part of the circuit that is to be protected. The arrester is used only when there is danger from lightning, and during this time the line to be protected is in actual connection with the ground, so that a lightning discharge does not have to jump an air gap in order to get to the earth. An air-gap arrester requires an abnormal potential to force the

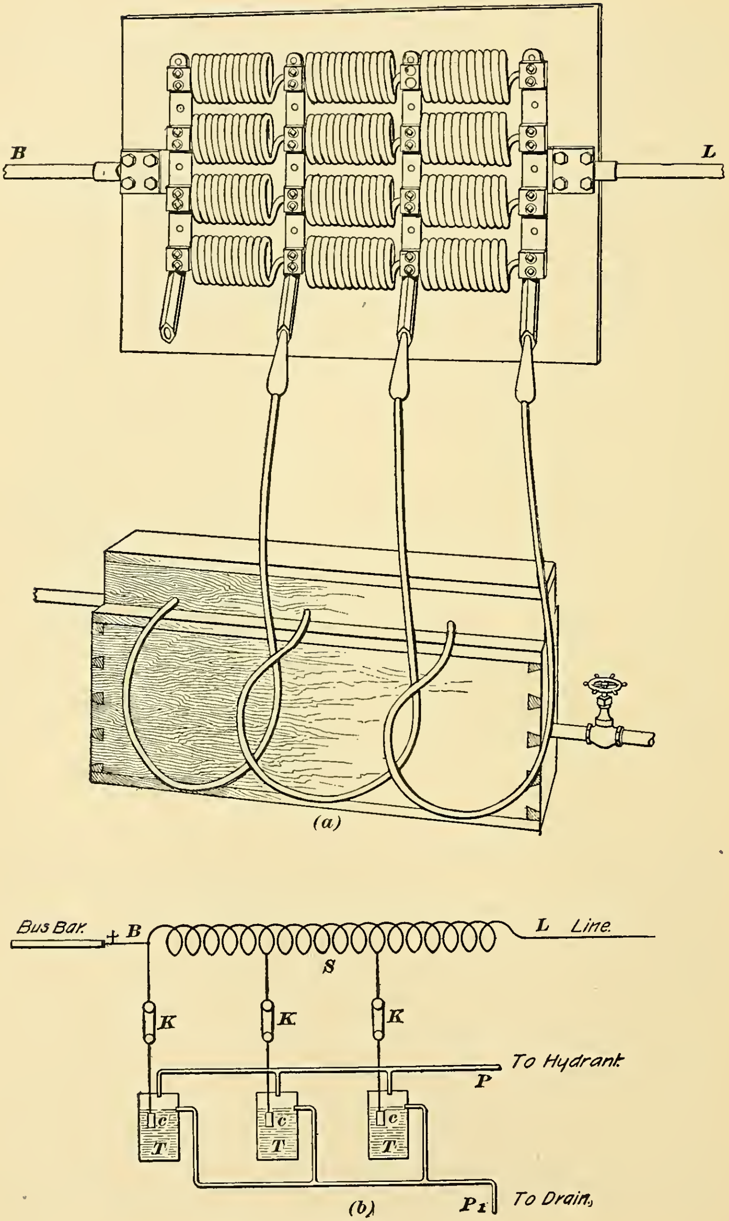


FIG. 4.

discharge across the gap; but the tank arrester works all the time and equalizes the line potential before it has a chance to reach a dangerous value. The strong point in favor of a tank arrester is that it passes off the induced charges due to overhanging clouds before they give rise to a line pressure high enough to cause a strike. The tank consists of three chambers *T*, *T*, *T* (*b*), each of which is kept filled with water by means of a stream that flows in at the same rate as it is allowed to flow out through an iron pipe to earth. Plunged into the water of each tank is a block of carbon *c* that connects directly to the device to be protected. The coil *S* shown in the figure constitutes a choke, or reactance, coil that makes the lightning pass through the arrester to ground in preference to going through the machine to ground. In Fig. 4 (*b*), the end *B* of the choke coil is connected to the + bus-bar and all on the station side of the choke coil is protected. *L* is the line or feeder over which the discharge of lightning is apt to come in. Plugs *K* connect the several sections of the choke coil to the several tanks in such a way that the choke-coil sections are all in series, and the tanks offer successively three different paths to earth, so that if a discharge misses the first tank, it still has the second and third tanks through which to reach the earth. The carbon plates are the positive pole of the arrester, the tanks and water the negative pole. It is thus seen that when the plugs are in place there is a direct connection from the line through the water to the ground. Current, therefore, flows through the arrester all the time it is connected, and for this reason it is only used when there is danger from storms. Of course, this arrester wastes a certain amount of current (about 3 amperes for each carbon in use), but it gives efficient protection, and the waste of current is a small item compared with the damage that might be done if the lightning discharges were not carried off.

7. Where ordinary air-gap arresters are used, each feeder should be equipped with one. Sometimes these feeder arresters are placed on the back of the board, but more often they are placed at a point near where the feeders enter the station and may be either inside or outside of the station. In addition, each generator is usually equipped with its own arrester, which is mounted on the back of the generator panel.

SWITCHBOARD CONNECTIONS.

8. The various devices that go to make up a railway switchboard have been considered, and we will now look at the connections necessary for an ordinary board. Of course, switchboards may differ considerably in their connections and yet accomplish the same purpose, so that it is not possible to lay down any fixed rules regarding them. Fig. 5 shows connections suitable for a board similar to the one shown in *Electric Railways*, Part 1. The various devices have been numbered to correspond in the two figures, and a number of minor fittings and connections have been omitted in order not to confuse the drawing; for example, connections are not shown for the switchboard or instrument lamps or for the exciting circuit of the Thomson ammeters; if Weston instruments were used, these latter connections would not be required. Only two feeder panels are shown, as the connections for all of them are alike. In this diagram the equalizer switch *E* is shown mounted on a stand near its machine, as this is the practice followed in the more recent plants. The + and – leads from the generators lead directly to the lower posts of the main switches. The upper posts of the + switches connect directly to the + bus-bar *A*. The upper posts of the – switches connect, through the ammeter shunt *B* and circuit-breaker *C*, to the – or rail bus-bar *D*. Note that the ammeter and circuit-breaker are not connected in the + side. This is because the equalizer is connected to the + side and the machine might be sending current through the equalizer, in which case the current in the + side on the switchboard

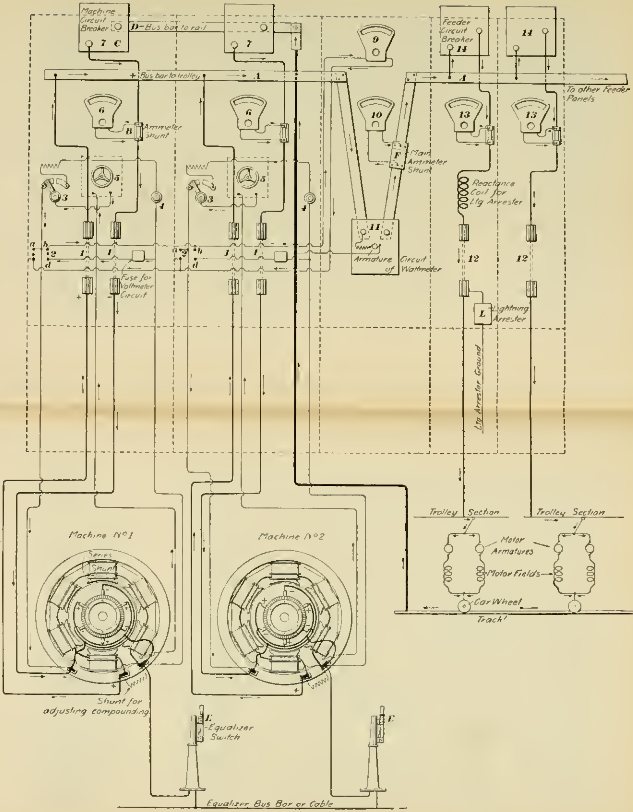

Machine Circuit Breaker
7
C
D–Bus bar to rail
7
9
Feeder Circuit Breaker
14
14
+ Bus bar to trolley
A
A
To other Feeder Panels
6
B
Ammeter Shunt
6
10
13
13
F
Main Ammeter Shunt
Reactance Coil for Ltg Arrester
5
3
4
5
3
4
11
a
b
2
1
1
d
a
2
b
1
1
d
Armature Circuit of Wattmeter
12
12
Fuse for Voltmeter Circuit
L
Lightning Arrester
Ltg Arrester Ground
Trolley Section
Trolley Section
Motor Armatures
Motor Fields
Car Wheel
Track
Machine No 1
Machine No 2
Series
Shunt
Shunt for adjusting compounding
E
Equalizer Switch
E
Equalizer Bus Bar or Cable

FIG. 5.

would not be the total current delivered by the machine. Under such circumstances, an ammeter connected in the + side would not give true indications. Of course, the equalizer will work all right no matter whether the pole it is connected to is + or −, the only condition being that it must connect together the points where the brushes are connected to the series winding.

The + bus-bar *A A* is carried through the wattmeter as indicated at *11*, so that the whole current passes through *11* on its way to the feeder panels. The shunt *F* for the total-output ammeter *10* is also connected in series with *A* between the generator and feeder panels, so that *10* indicates the total current.

The voltmeter is connected to either machine by means of the plug receptacles *a*, *b*, *c*, *d*; *a* and *d* are in each case connected to their respective dynamo terminals, while *c* and *b* are connected to the voltmeter. When the plug is inserted, *a* is connected to *c* and *b* to *d*, thus giving a reading. Note that a voltmeter reading may be obtained even if the main switches are open; this is essential, because the voltage of a machine must be adjusted before it is thrown in parallel with another.

On the feeder panels, the circuit-breaker, ammeter shunt, and feeder switch are simply connected in series. If a lightning arrester is used, as indicated on one panel at *L*, the connection between the ammeter shunt and the feeder switch is usually coiled up, as shown, in order to form a reactance, or choke, coil to help keep the lightning discharge out of the machines.

SPECIAL ELECTRICAL APPLIANCES.

9. In describing the foregoing apparatus required for the power station, we have considered only that to be found in the ordinary station operating at 500 volts and supplying the current direct from the machines to the various parts of the system. On some roads, however, special conditions arise where one or more of the feeders have to run to points much farther distant from the station than others. Almost every power station has several feeders running from the bus-bars out to different sections of the trolley wire. Some of these feeders will be short and there will not be very much drop in them ; others will be long and the line loss in them may be so great as to seriously interfere with the operation of the cars on the distant sections of the road. Of course, the voltage of the bus-bars in the power station could be raised by raising the voltage of all the dynamos that feed into them, but this would also raise the voltage on the short feeders that do not require a high voltage. In order to supply a high voltage to those feeders that require it, a number of different schemes are used.

10. Use of Auxiliary Bus-Bar. — Fig. 6 shows one method that is available when one of the machines in the station can be set apart for the supply of these high-voltage feeders. It consists simply in supplying the feeder boards with an additional bus-bar *B*, which is connected to machine *C*. This machine, for example, might generate 650 volts, while the regular machines feeding into + bus-bar *A* generate the usual 500 volts. The feeders are connected to double-throw switches *F*, so that they may be run on either the high or low bus ; hence, if any feeder is heavily loaded or if it runs to an outlying point, it may

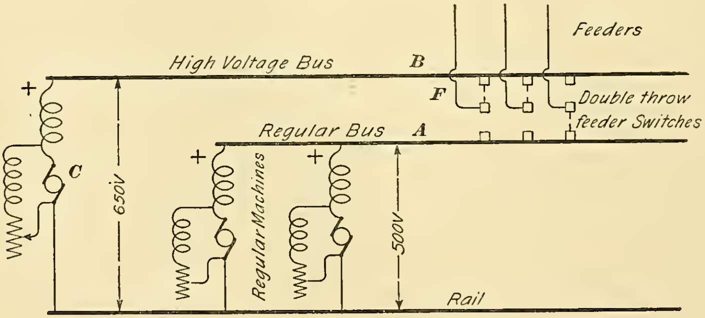


FIG. 6.

be connected to the high-voltage machine *C* by throwing its switch up; at the same time the other feeders would be supplied from *A* at the usual voltage.

USE OF BOOSTERS.

11. A separate machine is not always available for use, as described in the last article, in which case a **booster** is generally employed to raise the voltage for those feeders that require it. The term booster is used in railway work for a number of different appliances. It is used to designate a machine to raise the voltage on outgoing feeders, and it is also used in reference to the machine for regulating the charge and discharge of storage batteries. In all cases, however, the term booster carries with it the idea of a machine for changing voltage, and we shall now consider only the type of machine used to increase the voltage supplied to outgoing feeders; the storage-battery booster will be taken up later.

12. Let us take the case of a single large dynamo feeding into a pair of street-railway bus-bars from which run out a long feeder and a short one, as shown in Fig. 7. In this figure, *A* represents the power-house dynamo feeding into the two bus-bars *a b* and *c d*. Running out from the positive bus-bar *a b* are two feeders *e* and *f* that supply the two sections of trolley wire *C* and *D*, respectively. *M* is a car somewhere out on the line. Feeder *e* is so short that no excessive drop in voltage takes place through it, so that it does not require an increased voltage; but feeder *f*, being much longer, does. In order to supply the additional voltage, the armature of a dynamo *B* is connected in series with the feeder *f*. Any kind of dynamo can be used as a booster, but some dynamos are much better adapted to this service than others. The series dynamo is used most largely for this work in railway plants, because, between certain limits of load, its ability to add voltage to the circuit increases directly as the demand made upon it. In other words, all the current that goes through the feeder passes also through the series field of the booster and enables it to generate voltage in proportion. It is easy to see, then, that since the booster must carry the entire load of the feeder or feeders with which it is in series, its current capacity must be equal to the entire current required by the cars that run on the trolley sections fed by the feeder or feeders connected to the booster. Although the current capacity thus has to be large, the voltage generated by the booster is usually only a fraction of that generated by the main dynamo, so that the *watts* output of the booster may be considerably less than that of the main dynamo. In many instances, special switches have been provided, so that one of the regular 500-volt dynamos, running ordinarily as a dynamo in multiple on the bus-bars with the other dynamos in the station, can be cut out of the regular dynamo service and cut into series with one of the feeders as a booster. Where a dynamo can always be spared for such service, such an arrangement saves the expense of buying a special machine for the work. It is rarely the case, though, that a feeder requires to be boosted as much as 500 volts. The number of cars supplied by the feeder may call for the full current-carrying capacity of the available 500-volt compound-wound dynamo, but need not call for its full voltage. In such a case, it is the custom either to cut out the shunt field on the dynamo and resort to the series field alone or to use some special method of

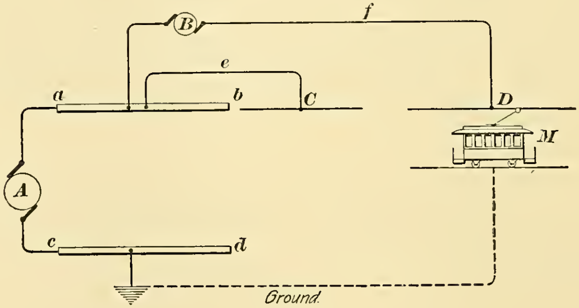


FIG. 7.

separately exciting the shunt field to any desired degree and supplement its field with that due to the series coils. It is easily seen that a dynamo that is run at normal current, but under the normal voltage, is not running at full load, and is not, therefore, running with the greatest attainable economy. The question of connections for a *convertible booster and dynamo* will be taken up later.

13. Boosters for use in railway service can be bought specially wound to handle any current at any voltage to suit the conditions of the particular service to which they are to be put. Such machines are usually designed to run from a steam engine direct-connected or from a motor whose armature is coupled to the same shaft and whose bedplate supports the frame of both machines. The booster plant can be installed in the power station itself or it can be put out on the line. On account of the cost of attendance, the power station is the best place for it, unless there are conditions that prohibit its being placed there. Where each feeder supplies its own section of trolley wire, as shown in Fig. 7, it makes no difference where the booster is located so long as it is in series with the feeder, because the booster can never be called on to carry any current except what goes to section *D*. But on such feeder construction as that shown in Fig. 8, it makes a great difference, especially to the booster itself, where it is placed. In Fig. 8, several sections of trolley wire *a*, *b*, *c*, *d* are connected to the same feeder *f f*. If the booster is cut in at *B*, it must carry the current

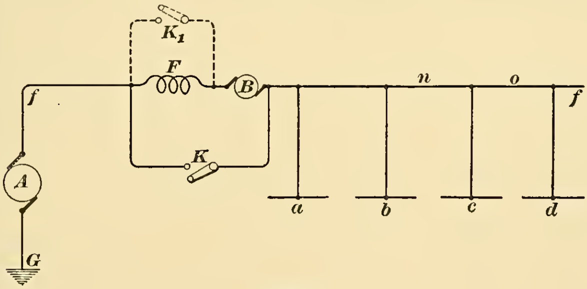


FIG. 8.

called for on all four sections; if it is cut in at *n*, it will carry the current for the *c* and *d* sections only; while if it is cut in at *o*, it will have to carry only the current that goes to section *d*; so that a booster put into a feeder at *B* would have to have four times the current-carrying capacity of one put in at *o*. Most feeder work at the present time is laid out after the plan shown in Fig. 7, so that the booster can be placed in the power station as well as not.

14. Operation of an Engine-Driven Booster.—The same rules that are observed in the care and operation of a dynamo of any other kind hold good in the case of the booster; but on account of its unusual relationship (being in series) to the rest of the circuit, it has some peculiar points not found where dynamos are run in multiple. In the first place, great care must be taken to connect the machine properly, so that it will add its voltage to that of the power house. The polarity of the booster may be determined by means of a voltmeter, as this is the most convenient method. We will suppose that the booster, which is a series machine, is not connected in circuit, but is running at about half speed. Short-circuit its terminals with a piece of light fuse wire, so that it may be able to generate and at the same time note the direction in which the needle of a voltmeter attached to the terminals deflects. The negative terminal of the booster must connect to the power-house end of the feeder and its positive terminal to the line side of the feeder; for it must be borne in mind that connecting the booster in series with the feeder is really connecting it in series with the dynamos that supply the power-house bus-bars, from which the feeder draws its current, so the positive side of the generator must go to the negative side of the booster. After the circuit is once closed by connecting in the booster, the line current dictates the polarity of the booster voltage, so this polarity cannot be wrong, unless the machine itself is incorrectly connected. Since for given connections, the booster, like any other dynamo, can generate only for one direction of rotation, it follows that if the direction of rotation proves to be such that the machine cannot be made to generate even on short circuit through the light fuse wire, either the field or armature terminals must be reversed or the booster must be turned end for end so that the direction of rotation of the armature may be reversed. If the booster is direct-connected to the engine, turning it end for end is of course impracticable, so that it is best to reverse the connections of the field or armature. If the booster is direct-connected to a motor, the best plan is to reverse the shunt field on the motor.

Reverting to the engine-driven booster: since the booster is a series machine and since series machines run in the opposite direction as motors from what they do as dynamos, the connections remaining the same in both cases, the effect of throwing the booster into service with either its field or armature leads crossed would cause it to keep on running in the same direction as a motor, with the result that, instead of boosting the voltage of the feeder, it would insert in the circuit a counter E. M. F., the amount of which would depend on the value of the current in the feeder; in this case, the voltage in the feeder would be made less instead of greater. The next mistake possible is, after getting the fields and armature of the machine properly connected, so that the machine can act as a dynamo, to get the dynamo as a whole cut into the feeder electrically wrong end to, so that its polarity opposes that of the dynamo supplying the feeder.

15. Cutting the Booster In and Out.—The principle involved in cutting a booster in and out of service is very much the same as that used to cut in and out arc-light dynamos that run in series on the same load. As a matter of fact, the feeder, or the dynamo that supplies it, and the booster are just as much in series as are two arc-light dynamos on a lamp load. In Fig. 8, *B* and *F* are the armature and field, respectively, of the booster connected in series with the feeder at the power house and driven by a steam engine not shown. *K* is a switch across the outside terminals of the booster and K_1 is a switch across the terminals of its field. There are several ways of rendering a booster electrically inactive. One way is to short-circuit its field by means of a switch connected across it, as shown at K_1. In this case, the armature continues to carry the same amount of current as the feeder, but even if the booster engine is kept turning at full speed, the pressure of the feeder current is not raised any, because, since the field is cut out, no voltage is generated within the armature itself.

Another way to cut the booster out of active service is to simply short-circuit the field and shut the steam engine down; in this case, the feeder current continues to pass through the armature of the booster, and to avoid unnecessary drop and heating, it is well to provide a switch such as K, so that the whole machine can be cut out *after* it is shut down. Under no circumstances should the switch K be closed while the booster is up to speed, for, since the machine is connected to generate, the effect would be to have it act as a dynamo on short circuit through the local path K–F–B–K. Nor should the engine be started up with K closed unless K_1 is closed also, because the same thing will happen.

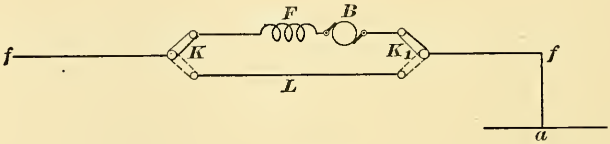


FIG. 9.

The safest arrangement of all is to install a combination switch that will open the booster circuit at both ends and put a bar of copper in its place to close the circuit. Such a switch is shown in the sketch in Fig. 9, where $f\ f$ is the feeder; a, the trolley section that it feeds; $F B$ is the booster; and L is the bar of copper. K and K_1 are two double-throw switches, shown at opposite ends of the booster in the diagram, but in practice they are mounted on the same base plate and operated by the same handle. When the switch blades are in the full line position, as shown in the figure, the booster is in service; but when the switch blades are thrown down to the dotted position, the booster is cut out at both ends and the copper bar L takes its place. This method has the advantage that the machine is entirely cut out and *dead*, as it is termed.

16. Motor-Driven Booster.—When a motor is used to drive the booster, the shunt-wound type of motor is invariably selected, because it runs at practically constant speed no matter what the load on it may be. As far as the booster itself is concerned, it does not matter whether it is driven by a motor, a waterwheel, or an engine as long as the speed is kept up so that it can provide an E. M. F. proportional to the current demand on the feeder. On the other hand, the use of a motor for driving widens the field for electrical troubles in so far as the motor takes the place of the steam engine. Especially is this the case where the booster unit must be placed out on the line. In either case, whether the booster is in the power house or out on the line, the motor is connected in the same way as any other shunt motor; that is, there must be facilities for starting and stopping it and also for protecting it in case there is trouble on the line. As shown in Fig. 10, the booster as a whole is put in series with the feeder, and the motor as a whole is put across the line, i. e., between the trolley and ground. In this figure, M is the motor armature, which has the starting box S in series with it; f_1 is the shunt field of the motor; $f\,f$ is the feeder supplying trolley section a; D is the booster armature; f_2 is the series field, and G is the ground or rail return. If the booster unit is out on the line, it is not difficult to see

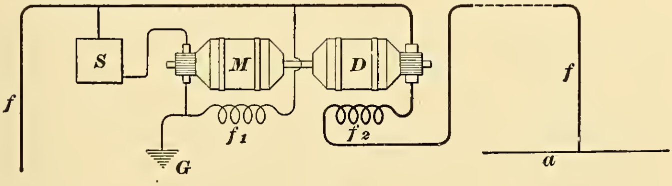


FIG. 10.

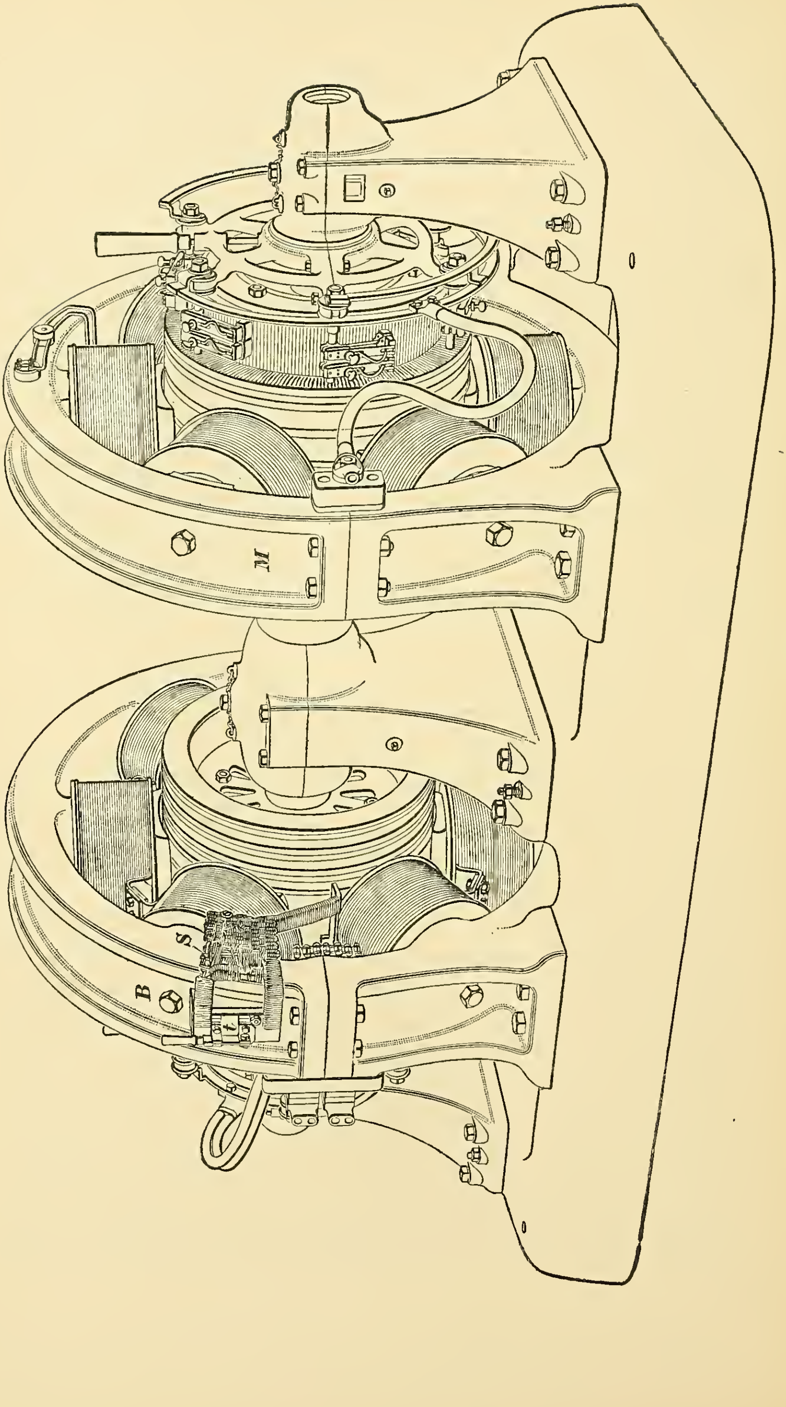


FIG. 11.

that trouble might be brought on some time by the power going off the line, in which case the motor would stop, as there would be no power to run it. Then, when the power comes on again, the motor being across the line, produces a prolonged short circuit. There would be an abnormal flow of current through the armature because the motor would be standing still and generating no counter E. M. F. On this account, when the booster is put in a place removed from the power house, it must either have attendance all the time or it must be provided with very refined devices for starting and stopping it in time of trouble.

As a rule, though, in present practice, if a single feeder is to be boosted and the additional E. M. F. required is not too great, the boosting is done by putting one of the regular dynamos, compounded to a high degree, on the feeder. It is sometimes the custom to put the booster in series with several feeders which run out about the same distance from the power house or whose load demands are, for other reasons, about the same, in which case the booster cannot be put out on the line, but must be put in the power house, where it can be cut in at a point common to all the feeders to be boosted. When the booster is installed in the power house, the fields of the motor are excited from the station bus-bars, and, as a rule, the motor armature is operated from that source. The booster field and armature are, as usual, put in series with the feeder or feeders to be boosted. Fig. 11 shows a type of motor-driven booster made by the General Electric Company. There are two separate armatures, each of which has its own frame and pole piece, but the two frames are mounted on the same bedplate. M is the shunt-wound motor driving the series booster B; S is a shunt across the field of the booster, which can be cut in or out of service by means of switch t.

17. Convertible Booster.—As previously mentioned, it sometimes becomes desirable to adapt one of the regular station dynamos to booster use. In such a case, provision is made so that the machine can be used either as a dynamo in the regular service or as a booster to raise the voltage on a feeder or group of feeders.

In Fig. 12, *L* is the power-station dynamo; its positive terminal goes to the positive bus-bar, marked + in the figure. The negative terminal of the dynamo connects to the negative bus-bar; and the junction of the dynamo series field and brush holder is connected to the equalizer bus-bar, used only when more than one dynamo is carrying the load. In the lower right-hand corner of the figure the booster is shown. *F*, *F*, *F*, *F* are the series coils of the booster and f_1, f_2, f_3, f_4 are the shunt-field coils. The circle *A* in the center is the booster armature. G_1 G_2 G_3 is the generator switch. The switch *K*, with the numbered blocks, is used for connecting the machine either as a booster in series with the booster feeder or as a dynamo in multiple

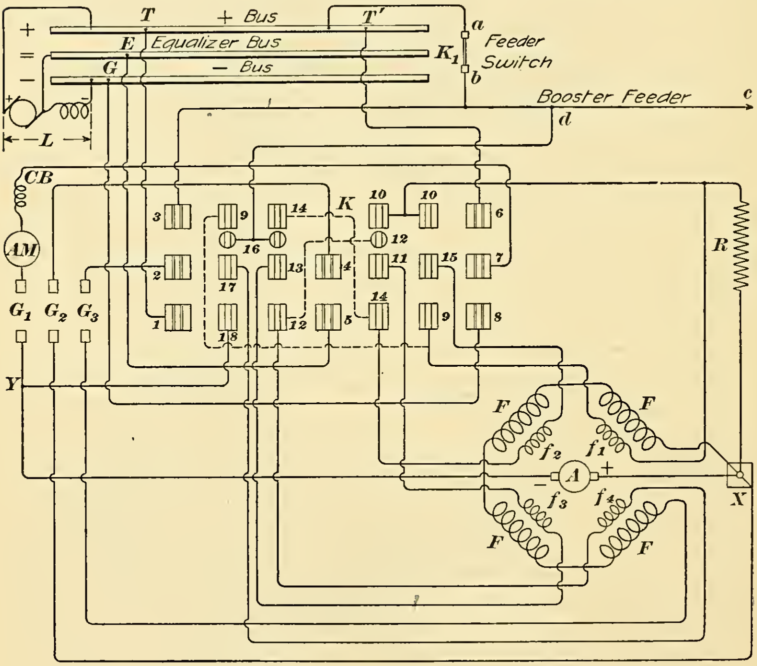


FIG. 12.

with dynamo L or whatever other dynamos may be carrying the load. When the switch K is thrown up, the machine acts as a booster, but before it can do so the feeder switch K_1, which short-circuits it, must be opened. When switch K is thrown up, block *2* connects to block *3*; block *7* to *6*; blocks *9*, *14*, *16*, *17*, and *13* connect together; blocks *10*, *11*, *12*, and *15* connect together. It will be noticed that the series coils of the machine are all connected in series, the same as on any dynamo or motor; each shunt coil, however, has a pair of leads of its own, because when the machine is used as a booster, all the shunt coils must be in multiple, and when the machine is used as an ordinary dynamo, all the shunt coils must be in series as usual. The two ends of the booster circuit are T' and b; the two ends of the switch K_1 are a and b; points T' and a are practically the same point, being connected by a few feet of stout copper bus-bar. It is easily seen, then, that if switch K_1 is closed, the two ends of the booster circuit are brought directly together; in other words, the machine is short-circuited. When the switch K_1 is open, however, the only way that current from the positive bus-bar can get out on the line to the cars by way of feeder $b\ c$ is to go through the booster, which, if its polarity is right, adds its voltage to that of the line dynamos. Neglecting for the present the shunt field of the booster and assuming that switch K_1 is open, the path of the current through the power-station dynamo, the booster, and the booster feeder is $L+\ -T-T'-6-7-C\ B$ (circuit-breaker) $-A\ M$ (ammeter) $-G_1-A-\ -A+\ -X-F-F-F-F-G_3-2-3-c$ through the cars, back to the station by way of the rail to the negative side of L. When the switch K_1 is closed, the path of the current is $L+\ -T-T'-a-K_1-b-c$, and so on, the booster being cut out. The booster field is excited not only by the series coils, but also by the shunt coils, which are all in multiple, thereby greatly decreasing the resistance of the shunt-field circuit, so that it may be excited by being connected in parallel with a certain length of the feeder, and thereby subjected to the voltage drop in that length. One end of the f_1 shunt-field coil goes to block *9* and the other to block *10*. The ends of field coil f_2 go to blocks *14* and *15*; the ends of f_3 to blocks *11* and *13*; the ends of f_4 to blocks *17* and *12*. The result of this arrangement is that when the booster switch is thrown up, the positive ends of all the shunt coils go to one set of blocks that are connected together and the negative ends to another set of blocks that are also connected together. The positive ends go to blocks *10*, *11*, *12*, and *15*, which are all connected together by the switch blade when the switch is thrown up. The negative ends go to blocks *9*, *13*, *14*, and *17*. Double block *16* connects to the feeder at some point d, determined by the amount of feeder required to give the drop necessary to excite the fields sufficiently. Double block *16* connects to the negative ends of the fields when K is thrown up. Double block *10* connects to the positive ends of the fields when K is thrown up. The connecting wire from double block *10* leads through the field rheostat R and the block X to the positive side of the booster armature.

18. When the booster switch K is thrown down, blocks *2* and *1* are connected together; block *17* is connected to block *18*; block *13* to block *12*; *4* to *5*; *11* to *14*; *15* to *9*; *7* to *8*. In both positions of the switch, the large blocks are connected with the main booster circuit and the small blocks with the shunt-field coils. The two ends of the booster, which is now connected across the trolley and ground bus-bars as a regular generator, are T and G; the path of the booster current is $A+-X-F-F-F-F-G_3-2-1-T$, out on the line by way of the switch K_1 and the feeder c to the cars, through the motors to the rail, along the rail back to the ground bus-bar G in the power house, through $8-7-C\,B-A\,M-G_1-A-$. The current contributed by the booster joins the current contributed by the station dynamo L at point T. One end of the shunt-field circuit is at block X; the other end is spliced to the negative armature wire $A--G_1$ at Y, and the path of the current through the shunt field is $A+-X-R-f_1-9-15-f_2-14-11-f_3-13-12-f_4-17-18-Y$. The shunt coils are now all in series and the current flows through them in the same direction that it flows through the series-field coils.

19. Economy of the Booster.—The booster may be regarded as an electrical economizer, not in the same sense of the term that holds good when applied to such devices as a condenser for exhaust steam or the heater for feed-water used in a steam plant, because these devices effect a still further economy under conditions that are already comparatively good, but in the sense that at times it may relieve a hopeless condition that nothing else will without great cost.

Suppose, for example, that a certain section of a road is a long distance from the power house and operating with a large drop. The voltage at the cars will be low and they will run slowly. If a booster is installed, the voltage at the cars will be raised and they will run faster. The result will be that, while the current they draw from the power house may be nearly as large as it was before, because the series motor such as used on street cars takes a certain current for a given effort no matter what the speed may be, the cars will not require the current for so long a time; hence, more cars may be operated. The booster, therefore, actually increases the working efficiency of the system and improves a condition that could not be otherwise bettered without a very large expenditure for copper in the overhead feeders.

The booster, of course, requires power for its operation. This fact becomes more apparent when the booster is put out on the line and a motor used to run it; in this case, there is not only a loss within the booster itself, but there is an additional loss in transmission, because the booster motor draws current from the line at low pressure and gives it back to the feeder at high pressure, but the generator end of the booster can never give back to the line as much energy as the motor end takes out of it. The service rendered by the booster, however, cannot always be estimated by the amount of energy that it consumes. There are conditions under which no other means outside of a substation or a new power house will make the car service practicable. The feeder to be boosted may be so long as to render the addition of enough copper out of the question. On account of low voltage, and hence low car speed and unsatisfactory service in general, the public will refrain from riding on that part of the line except when they cannot help themselves. The addition of a booster will enable the cars to run on time and draw the travel. It is a well-known fact among street-railway men that for a given time table, low voltage on the line is much harder on the motors and controllers than high voltage, because, in the first place, the motorman must get his quick start by throwing the controller far around before the car has run any distance; and, in the second place, each car, instead of coasting, has to take current in order to make its time.

STORAGE BATTERIES IN CONNECTION WITH ELECTRIC RAILWAYS.

20. Storage Batteries on Cars.—The storage battery as applied directly to the running of cars and stationed on the cars themselves has not, for several reasons, scored the degree of success that it has attained in other lines of work, the main feature militating against the direct application of storage batteries being their excessive weight. One of the storage-battery traction systems that has most nearly approached success in America is that installed on the system now known as the Chicago Electric Traction Company. It is a fact beyond dispute that the overhead-trolley system is far more economical than the storage-battery system, and the Chicago advocates of the latter system do not claim otherwise, but they state that on their own line, where the erection of overhead work was not allowed by the city, the storage system has been operated on a profitable basis. They operate about 25 cars over a line 30 miles long, and for these 25 cars 40 batteries are provided. Each battery is composed of 72 cells and weighs, with its tray, about 3 tons. The motors are mounted on the outside of the axles, leaving the space between the axles for the tray of batteries. The weight of the batteries renders their handling a problem that has been very successfully and economically worked out by providing an automatic shifter, which does away with manual labor entirely in effecting a change of batteries. All connections are made automatically by means of spring contacts.

Each storage cell when fully charged gives an E. M. F. of 2.18 volts, so that 72 cells would furnish a voltage of $72 \times 2.18 = 157$ volts. Each car is provided with a single 50-horsepower motor wound for 135 volts, so the motor is subjected to an excess pressure of 22 volts, but seems to be in no way harmed by it. It is a well-known fact that the E. M. F. of a storage battery becomes less as the charge is paid out. In the case in question, the batteries are charged until their E. M. F. is 2.18 volts per cell and are allowed to run until the E. M. F. falls to 2 volts. During this drop in E. M. F., the car makes from 10 to 12 miles. The batteries would run the car farther than this, but experience has shown that this is the most economical run to get out of the car before recharging. As far as the actual running life of the batteries is concerned, this is limited only by the disintegration of the positive plates. The old-time weakness of buckling does not give any trouble on this road, but it is found to be a great advantage to thoroughly wash and clean the plates after the completion of each 4,000 miles. If the car averages 100 miles a day, this would mean a cleaning of the plates every 40 days, or, say, every month and a half.

In charging the batteries, a current of 160 volts pressure is first applied; as the charge increases and the E. M. F. of the battery rises, the charging voltage is raised to 170, and finally to 180 volts. The motors used on such a system as this must, of course, be especially designed for the lower voltage and the larger current. A 50-horsepower motor to be run on a 135-volt line calls for a current of $\frac{50 \times 746}{135} = 276$ amperes

—a current which, if it had to be transmitted to a distance for any number of cars, would cause a prohibitive line loss. In this case there is no line, and therefore no line loss, and on account of the low voltage, insulation breakdowns are very rare.

21. One of the most valuable features of the storage battery is its ability to deliver heavy currents for short intervals. It is therefore very valuable as an auxiliary in power plants or substations to steady the load carried by the dynamos or rotary converters. In almost all power houses there are certain times of the day when the dynamos are called upon to run at their full capacity in order to carry the load. At other times of the day, when the traffic is light, there may be very little demand on the dynamos and perhaps only half of them may be in use. The average load on the power house has a certain value, but the maximum load may be easily twice this value. It is easily seen, then, that while the machine capacity of the power house should be adequate to meet only the requirements of the average load in order to fulfil the best possible conditions of economy, yet, in order to meet the actual requirements of the service, it is necessary that the machine capacity of the power house should be able to cope with the maximum load; otherwise, just when it is most urgent that the cars should run on schedule time, the station will not be able to supply enough power.

In a small power house it is usually necessary that the machine capacity should be adequate to meet the demands of the maximum load. But in such a case, the actual amount of machine capacity represented by the difference between the maximum and average load is small compared to the difference between that of a large power house, and so does not amount to as much from a money point of view. In a large power house the difference between the maximum and average loads may amount to several thousand horsepower, and this represents a very heavy investment in the way of machinery that may be idle a great part of the time.

22. Methods of Using Storage Batteries.—One way of expressing the fact that the storage battery helps out the power-station dynamos during their period of heaviest load is to say that the battery takes the **peak** of the load. The method of carrying this out is about as follows: The storage battery as a whole is put in multiple with the dynamos, being connected to the same bus-bars; during the hours when the load is light, the dynamos not only supply the outside load, but they charge the battery as well. When the rush hours come on, the battery helps the dynamos on the outside load. In this way the engines and dynamos are kept more nearly at full load all the time.

Storage batteries may be installed either as an aid to the power-house dynamos, by taking the peak of the load and cushioning the violence of the fluctuations, or they may be placed at the end of a long line to keep up the voltage and obviate the heavy line loss incidental to supplying large currents from the power house through long feeders. In either case, the final effect is to relieve the power house of some of its load.

23. Battery Used to Take Peak of Load.—An example of this application is found in the storage-battery plant of the Buffalo Street Railway Company. The storage batteries are installed at the main power house for the purpose of cushioning the fluctuations and to carry the peak of the load. Now, the generators in such a station are heavily overcompounded, and their terminal voltage, therefore, varies according to the load; the battery is in multiple with the generators on the bus-bars. Also, since the E. M. F. of the generators increases as the load increases and since the E. M. F. of the battery decreases as the load increases, on account of its internal resistance, there must be some means provided for regulating the voltage of the battery to suit that of the bus-bars. This regulation is effected by means of a motor-driven booster connected in series with the battery.

This booster is designed to increase the effective voltage of the battery at the same rate as the load increases, thereby preserving the relationship between its E. M. F. and that of the generators. The positive end of the battery is connected to the positive bus-bar of the station; the negative end of the battery goes to one terminal of the booster armature, the other end of which goes to the ground. The motor end of the booster unit is a six-pole machine running at 500 revolutions per minute from the station bus-bars. The booster performs two duties: it regulates the voltage at which the battery discharges and it also helps to charge the battery. On this account, means must be provided for not only varying the voltage of the booster from zero to a maximum, but for reversing its polarity, because during a charge the current flows towards the battery, and during a discharge from it. This is done by means of a combination switch whose blade has three positions. In one of the positions, the polarity of the booster is such as to charge the battery; in a second position, the polarity is such as to discharge the battery; while in a third or neutral position, it is out of action.

The Buffalo road obtains its power from Niagara Falls as a three-phase alternating current, which is changed by means of rotary converters into a direct current for use on the railway. At night the rotary converters are used to charge the battery that is cut in on the line about 5.30 A. M. The battery itself is composed of 270 chloride cells, which at 2.18 volts each give a total of 270 × 2.18 = 589 volts. The battery has a capacity of 1,200 horsepower-hours, when discharged at the rate of 1,200 horsepower, in which case it would discharge in 1 hour. The cells are not full of plates, room being left for a future increase in the capacity to 2,000 horsepower at 1 hour's discharge. The containing tanks are made of wood, lined with lead, and are supported on porcelain insulators. The floor is made of concrete and slopes to one side to facilitate drainage. Insulating mats of wood are laid in the aisles between the rows of cells.

24. Battery Out on the Line.—An example of the second method of applying storage batteries to railway work is found on the South Side Elevated Road, of Chicago. The cars operated are quite heavy, and the power station is near the center of the road. There are two storage-battery plants, one near each end of the line. The trains are all equipped with the Sprague multiple-unit system. This system provides that each car in the train shall be a motor car and that all the motor cars can be operated simultaneously from either end of any car in the train. On starting, the train accelerates very rapidly, and in a few seconds is under full headway, so that during this time the flow of current is large and the strain on the feeders severe. The load units being large, the fluctuations in the load are of course violent. The storage batteries are connected directly across the line without the intervention of any booster, and they depend for automatic regulation on the variation in the drop that takes place in the feeders between them and the power house. The drop varies between 10 and 30 volts, according to the load. When the load is light, the drop is small, and the voltage of the feeder, being above that of the battery, sends a charging current through it. The battery consists of 248 cells, having a capacity of 1,000 horsepower at the 1-hour rate. When the load is heavy, the excessive drop brings the feeder voltage down below that of the battery, enabling the latter to send a current into the line, thereby aiding the power house. The automatic regulation of the charge and discharge of the battery requires that there be a certain amount of variation in drop. If it is found that a battery is called on to discharge more than it is charged, an extra feeder must be run between it and the power house to raise the feeder voltage in the neighborhood of the battery and thereby relieve the battery of some of the load. In the battery plants of the above-mentioned road, each battery is connected to the power house through two special feeders, so that by means of them the automatic regulation can be helped. If it is found that the battery does but little discharging, it means that its E. M. F. relative to that of the feeder must be raised. This can be done either by putting several more cells in series with the battery or by increasing the drop in the feeder itself. To do this, if there are extra feeders between the battery and the power house, as in the above case, one of them can be cut out. A battery used at the end of the line has the advantage of maintaining the voltage and enabling the cars to keep their schedule, besides relieving the generating apparatus and saving copper in the line. A drop of 10 per cent. in the lines is sufficient to allow the battery to operate automatically as above described. Of course, in all cases the line must be long enough and the load sufficiently heavy to justify the use of the battery; otherwise, no economy will be effected by its use.

25. Differential Storage-Battery Booster.—The action and use of the differential battery booster has already been explained. In this style of booster the whole output of the plant is carried through the series-field winding, and the battery charges and discharges according as the load on the line is light or heavy. This style of booster is generally used when the load on the line is rapidly fluctuating.

26. Compound Booster.—In cases where the battery is intended to take the peak of the load, which may extend over a considerable period, the compound booster is frequently used. This differs from the differential booster in that only the battery current passes through the series coils of the booster, as indicated in Fig. 13. A is the armature of the booster and F its series-field winding. G is one of the regular compound-wound generators feeding into the bus-bars; s, r, s', r' are the shunt fields and rheostats of the booster and generator. In this scheme of connections, it is seen that only the current furnished by the battery passes through F, and not the whole line current, as in the case of the differential booster. When the battery is carrying the peak of the load, the voltage across its terminals of course falls off as the current increases, on account of the internal resistance and also on account of the drop in voltage due to the cells becoming discharged. The booster voltage increases as the current delivered by the battery increases, and as this voltage is added to that of the battery, the result is that the voltage at the bus-bars is maintained and the battery takes its share of the load. When the battery is to be charged, the polarity of the booster may be reversed by means of field reversing switches and the booster made to generate a voltage of the opposite polarity, thus helping the generator to force current through the batteries. A booster of this type is used therefore when a battery is either to charge or discharge for a certain length of time, but where it has to discharge for short intervals and then charge for similar intervals, as it should on a load subject to sudden changes, the differential booster is used.

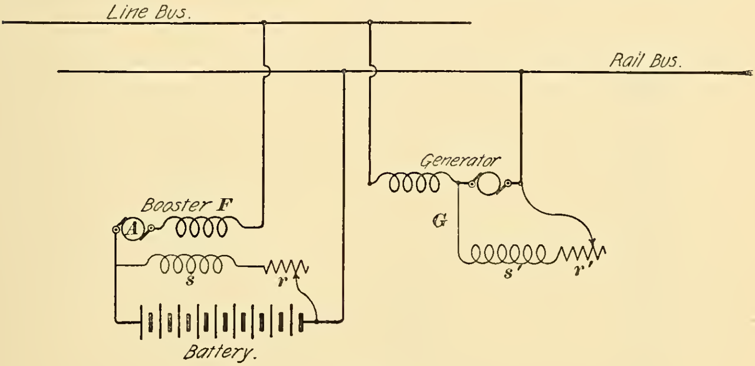


FIG. 13.

27. The effect of a battery in smoothing out the load line on a station is shown by Fig. 14. The heavy line indicates graphically the variation in the total current during a certain day. The lowest point, about 85 amperes, is reached between 3 and 4 o'clock in the morning; then it rises abruptly at 6 o'clock and continues to increase until 9, falling again towards noon, and attaining its maximum value at 6 in the evening, whence it falls rapidly and continuously. It is evident that to operate such a road, a plant would have to be provided with generators capable of furnishing 2,700 amperes to the line, and probably more on some occasions; but this amount is required during only a short period, and some of the plant must remain idle or work inefficiently for a greater part of the 24 hours. The average current is about 1,276 amperes, and a line drawn through this point indicates the current output if the load were steady all day and the same in total amount. It would obviously, then, be an advantage if the high parts of the load could be brought down and the low parts brought up, and an equalization of the load thus effected. The storage battery can do this. If it were installed in such a station, the dynamos would be called on to deliver only about one-half of the current, 1,300 amperes instead of 2,700 amperes, and would therefore have to be but one-half the size; the engines and boilers could also be correspondingly smaller. In the diagram, the shaded portion marked *c* represents the charge given to the accumulators; *d* represents the discharge. Of course, in actual practice it would be almost impossible to bring the load on the generators down to a straight line

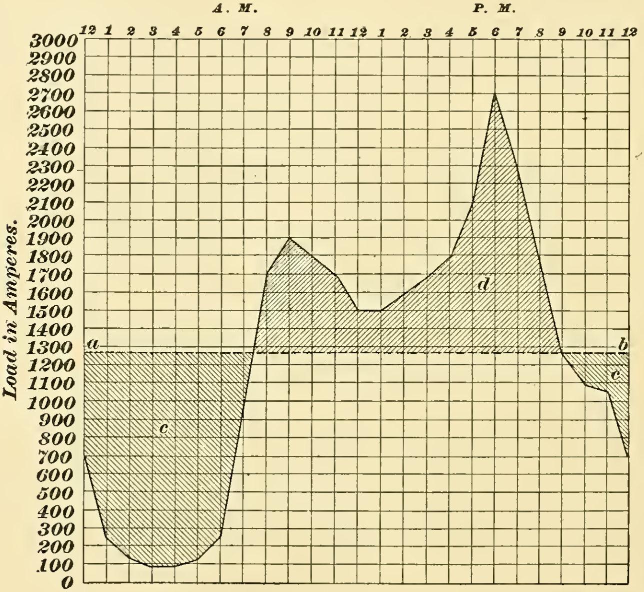


FIG. 14.

like *a b*, but nevertheless it may be made so uniform that the variations put but little strain on the machinery.

On small roads the fluctuations in load are especially severe. The upper curve, Fig. 15, shows the load curve taken from a small station. It is at once apparent that the load fluctuations are rapid and violent, as the curve represents a period of only 5 minutes. The lower curve shows how the load on the generators was smoothed out when the batteries were installed. The battery consists of 262 chloride cells. Each cell consists of 9 plates about 10½ inches square suspended in glass jars having outside dimensions of 10⅝ in. × 12½ in. × 15½ in. These jars are of sufficient size to permit of the addition of 4 more plates to the elements, thus insuring a 50-per-cent. addition to the capacity, should it be needed in the future. Each cell is on a wooden tray filled with sand and supported by glass insulators. On full charge, the battery has a capacity of 40 amperes for 7 hours; or it can discharge at the rate of 160 amperes for a short time. As a matter of fact, the battery is often called on to discharge at a rate far in excess of this, sometimes 250 amperes being called for momentarily.

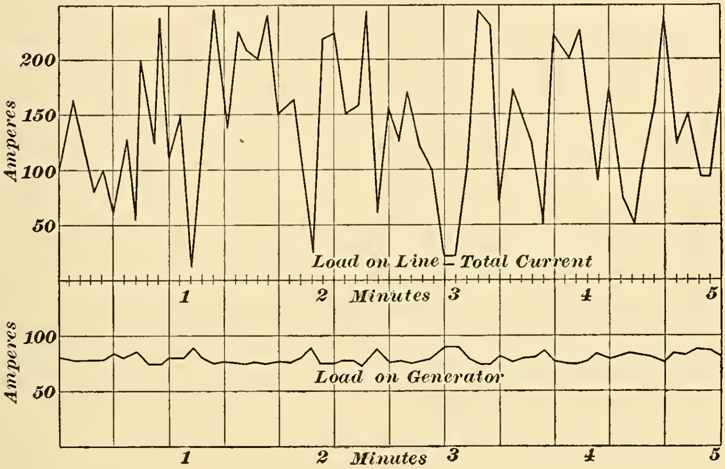


FIG. 15.

As a result of the heavy grades and the small number of cars operated, the fluctuations in the load are very violent. The power house is about ½ mile from the lower end of the road, in the center of the heaviest but not the longest grade. The machinery for generating the 500-volt direct current consists of one 60-kilowatt generator and one differential booster, both belted to the same engine. To clearly see the great advantage obtained by the use of the storage battery in this particular case, it will be best to study the load diagram given in Fig. 15, which was plotted from readings taken on the line and generator. These readings were taken every 5 seconds for a period of 5 minutes at the time of heavy load. It will be noted that the load on the line varied from about 15 amperes to about 250 amperes, but the load on the generators varied comparatively little.

Many other instances could be cited to show the position that the storage battery now holds in the electric-railway field. The batteries of today are made of liberal size for a given rated output and are mechanically strong, so that they are free from the old-time trouble of buckling. The plates are carefully prepared and live their natural time without dropping all their active matter in the bottom of the containing vessel. It is not to be imagined, however, that storage cells give no trouble and require no care, for, like all other electrical apparatus, they must be looked after if they are to give satisfactory service.

POWER ESTIMATES.

28. The problem of deciding what capacity the station dynamos must have in order to operate a given number of cars on a given road is a complex one, in that it involves conditions peculiar to each case and calls for the use of quantities that must to a great degree be guessed at or assumed. Among the factors that must be considered in solving the problem are: Weight of equipment; number of cars; speed of cars; topography of the road (grades, curves, etc.); character of traffic; condition of line and rail return; manner of handling the equipment.

29. Weights of Cars.—The weight of an equipment, not including passengers, depends on the length and style of the car and on the weight of the motors. A modern open car just as it leaves the painter, with no equipment on it save the roof, wall, and light wiring, weighs about 320 pounds per foot, measured over all. A 20-foot body, then, would weigh in the neighborhood of 6,400 pounds; a 30-foot body, 9,600 pounds; a 35-foot body, 11,200 pounds, and so on. An open car equipped with motors of the proper size will weigh about 650 pounds per foot. This gives a 20-foot car a weight of 13,000 pounds; a 30-foot car, 19,500 pounds; a 35-foot car, 22,750 pounds. In designating the length of closed cars, it is customary to measure between the outsides of the bulkheads (end walls) and not between the bumpers. A modern closed car just as it comes from the painter, free of equipment, weighs about 395 pounds per foot of length between bulkheads. With the proper sized equipment, closed cars weigh about 880 pounds per linear foot. It will thus be seen that closed cars weigh more per foot than open cars. Up-to-date equipments complete weigh about 300 pounds per horsepower. This includes motors, trucks, hand-brake rigging, etc. The above figures may not exactly fit all cases, nor should they be expected to; but they have been averaged from observations made on standard equipments and will give a fair idea as to the value of these quantities. To the dead weight of the equipment must be added the weight of the passengers.

30. Current Required for Operating Cars.—We will assume that the cars to be operated weigh, with their probable average load, 10 tons; that they are to average 14 miles per hour; and that 6 cars are to be operated. The road is assumed to be level and free from curves. Now, it is an experimentally determined fact that *to urge 1 ton along at the rate of 1 mile per hour on a level rail requires an expenditure of about .06 horsepower applied to the wheels of the car.*

The experiment, of course, was not made on a car weighing only 1 ton. It was actually determined from the power required to drive a car weighing several tons 1 mile per hour and the power per ton derived by dividing by the number of tons.

Allowing an efficiency of 70 per cent. between the trolley wire and the rail would mean that, in order to get .06 horsepower applied mechanically to the car wheel, it would be necessary to apply to the motors electrically $\frac{100 \times .06}{70} = .086$ horsepower. Now, .086 horsepower $= .086 \times 746 = 64.156$ watts, which at 500 volts means a current $= \frac{64.156}{500} = .128$ ampere. Then, to push 1 ton of weight along a level rail at the rate of 1 mile per hour requires the absorption of .128 ampere at 500 volts. Now, the amount of current required to run a car is proportional to its weight, and within certain limits it is almost proportional to its speed. To push a 10-ton car along at the rate of 1 mile per hour would require a current of $10 \times .128$ ampere $= 1.28$ amperes, and to push the 10 tons along at the rate of 14 miles per hour, the assumed average speed, would require a current of 14×1.28 amperes $= 17.92$ amperes. As there are 6 cars and each car averages 17.92, say 18 amperes, to run the 6 cars would require a current of 6×18 amperes $= 108$ amperes, and this would represent the theoretical capacity of the dynamo required to run the road. Practically, this would be figuring too close, as there are times when one car alone will take as much current as this, if the controller is handled poorly, with the result that if the circuit-breaker were set so as to be any protection to the dynamo, it would be constantly flying out and delaying traffic. A dynamo of twice this current capacity would be more in order; then there would be some margin to allow for extra cars and increased headway.

The larger a system is, the nearer together may the theoretical and practical values of the station output be made, for then the fluctuations of a single car are not as large a percentage of the total load. For example, one of the cars above averages 18 amperes, but if there were only one car on the road and the breaker were set to act at 18 amperes, it would be impossible to start that one car at all.

31. Current on Grades.—It is useful to know also that the current taken by a car is almost directly proportional to the steepness of the grade that it may be ascending. It is easily seen that it cannot be exactly proportional, because a 1-per-cent. grade is infinitely steeper than a 0-per-cent. grade, or level. The approximate relationship is this: *If it takes .128 ampere to push 1 ton along a level at the rate of 1 mile per hour, it will take approximately 10 × .128 ampere to push it up a 10-per-cent. grade at the same rate.* On the lower grades this relationship is not as true as it is on the higher ones.

32. Formulas for Power Estimates.—The figures just given will be found to give approximately close results. A number of formulas have been devised to calculate the power required by cars under certain conditions, but it is evident that any such formulas are at best only approximate, because several elements always modify the power taken. For example, the running gear may be in bad shape or the motors may be inefficient; the roadbed may be in bad condition or there may be excessive friction on some of the curves. Tests on different cars might therefore lead to results varying considerably from those given by the formulas that follow.

33. Force Required to Move Car on the Level.—The drawbar pull per ton weight required to move a trolley car on a level track at a uniform speed is somewhat higher than on steam roads. It will generally require a horizontal effort of about 25 pounds per ton to keep a car moving uniformly, and it will of course take a much greater effort than this to start the car, because the friction of rest is greater than the friction when the car has once started to move.

For obtaining the horizontal effort applied to the wheels, we may use the formula

$$f = 25\ w_t, \qquad \textbf{(1.)}$$

where f = force in pounds,

and w_t = weight of car in tons.

That is to say, *the force required to move a car over a level track in average condition is 25 pounds for every ton that the car weighs.*

Example.—What force will be required to move a car, its weight being 9 tons?

Solution.—The weight of car $w_t = 9$ tons, and the force required will be, by formula **1**,

$$f = 25 \times 9 = 225 \text{ lb.} \quad \text{Ans.}$$

34. When a grade has to be taken into account, the perpendicular distance in feet ascended in 1 minute multiplied by the weight of car will give the power in foot-pounds expended in raising the car; the horizontal distance in feet traveled in 1 minute multiplied by the force in pounds necessary to move the car will give the power in foot-pounds required for a level track. The sum of these values divided by 33,000 will be the total horsepower at the wheels. Loss of power in the transmitting mechanism will necessitate a larger figure for the power supplied to the motors, this depending on the efficiency of the apparatus. We may express these several operations in a single formula, as follows:

$$H = \frac{h\,w + D\,f}{33{,}000\ \mathsf{E}}, \qquad \textbf{(2.)}$$

where

H = total horsepower required for motors;
h = perpendicular distance in feet ascended in 1 minute;
w = weight of car in pounds;
D = horizontal distance in feet traveled in 1 minute;
f = force in pounds necessary to move the car;
E = motor efficiency expressed as a decimal part of 1.

The horsepower required to propel a car up a grade is equal to the product of the height in feet ascended and the weight of car in pounds plus the product of the horizontal distance in feet traveled per minute and the force in pounds necessary to move the car, this sum being divided by 33,000 times the motor efficiency expressed as a decimal part of 1.

Example.—If a car with passengers weighs 8 tons and it is desired to take it up a 6-per-cent. grade at a speed of 10 miles per hour, what horsepower must be delivered to the motors, assuming that the efficiency between the trolley and wheels is 70 per cent.?

Solution.—The car will cover in 1 minute $\frac{10 \times 5{,}280}{60} = 880 \text{ feet} = D$, and on a 6-per-cent. grade this will correspond to a vertical distance of $880 \times .06 = 52.8 \text{ feet} = h$. The weight of the car expressed in pounds $= 8 \times 2{,}000 = 16{,}000$ pounds $= w$. The force required for propulsion is, by formula **1**, $f = 25 \times 8 = 200$ pounds, and the efficiency being 70 per cent., $\mathsf{E} = .70$.

Then, by formula **2**, we have

$$H = \frac{h\,w + D\,f}{33{,}000\,\mathsf{E}} = \frac{844{,}800 + 176{,}000}{23{,}100} = 44 \text{ H. P. approximately. Ans.}$$

35. It will be of interest to work out this problem by using the data given in Arts. **30** and **31**. The efficiency has been taken as 70 per cent. in both cases; so we will take the current as $6 \times .128$ ampere per ton weight per mile per hour. The total current would then be $6 \times .128 \times 8 \times 10 = 61.44$ amperes. At 500 volts, this would be equivalent to $\frac{61.44 \times 500}{746} = 41.2$ horsepower. This comes out somewhat smaller, owing no doubt to the approximation introduced by taking the power as directly proportional to the grade. For approximate calculations, however, the agreement is sufficiently close.

36. The *power* required in going around curves depends on their radius and on the construction of the truck. The power required for starting may be taken as the same as that for rounding curves.

37. It has been found that a *force* of about 70 pounds per ton weight of car is required to start a car or to keep it in motion when rounding curves. When starting on a grade, the effort must be greater in proportion to the percentage of rise, and for this condition add 20 pounds to the 70 pounds for every ton weight for each 1 per cent. of grade.

Expressed as a formula, the force required will be

$$f' = (70 + 20\,x)\,w_t, \qquad \textbf{(3.)}$$

where f' = force in pounds;
x = per cent. grade;
w_t = weight of car in tons.

The force in pounds required to start a car on a grade is equal to the weight of the car in tons multiplied by 70 plus 20 times the per cent. grade.

On a 2-per-cent. grade the force required in starting will therefore be $f' = [70 + (20 \times 2)] \times 1 = 110$ pounds per ton.

Example.—What force will be required to start an 8-ton car on a 5-per-cent. grade?

Solution.—According to formula **3**, the force will be

$$f' = (70 + 20\,x)\,w_t = [70 + (20 \times 5)] \times 8 = 1{,}360 \text{ lb. Ans.}$$

38. The limit of adhesion may be $\frac{1}{8}$ of the weight; therefore, on a level track the maximum force that could be applied without slipping would be $\frac{2000}{8} = 250$ pounds per ton. If the rails were muddy or greasy, much less than this force would be used, while very clean, dry rails might increase this amount. In ordinary street-railway service the rails are usually rather slippery, and often, in consequence, the adhesive force may be low. We may calculate the grade on which slipping will occur when starting the car and also when it is already in motion in the following manner:

Let a = ratio of adhesive force to weight on drivers;
w' = weight on drivers in pounds;
w_t = weight of car in tons of 2,000 pounds;
G_s = per cent. grade at which slipping occurs.

Then, slipping will occur at starting on a grade

$$G_s = \frac{a\,w' - 70\,w_t}{20\,w_t}.$$

But $w' = 2{,}000\ w_t$, when the whole weight of the car is on the drivers, in which case the limiting grade for starting

$$G_s = \frac{2{,}000\ a\ w_t - 70\ w_t}{20\ w_t} = \frac{2{,}000\ a - 70}{20} \text{ per cent.} \qquad \textbf{(4.)}$$

The limiting grade for starting a car, when the whole weight of the car is on the drivers, is equal to 2,000 times the ratio of adhesive force to weight on drivers minus 70, this difference being divided by 20.

When $\frac{1}{y}$ of the weight is on the drivers,

$$G_s = \frac{\frac{2{,}000\ a}{y} - 70}{20} \text{ per cent.} \qquad \textbf{(5.)}$$

The limiting grade for starting a car, when a fraction of its weight is on the drivers, is equal to that fractional part of 2,000 times the ratio of adhesive force to weight on drivers minus 70, this difference being divided by 20.

EXAMPLE.—If a car weighs 7 tons and all its weight is on the drivers, adhesion being $\frac{1}{8}$ of this weight, will it start on a 7-per-cent. grade?

SOLUTION.—The per-cent. grade at which slipping occurs at starting is, by formula **4**,

$$G_s = \frac{(2{,}000 \times \frac{1}{8}) - 70}{20} = \frac{180}{20} = 9 \text{ per cent.}$$

The car will therefore start on a 7-per-cent. grade, as 9 per cent. is the limit. Ans.

39. When the car is running, only 25 pounds per ton is necessary for propulsion, and the limit of grade which may be ascended is, when G_r = maximum grade which a running car will ascend,

$$G_r = \frac{\frac{2{,}000\ a}{y} - 25}{20} \text{ per cent.} \qquad \textbf{(6.)}$$

The limiting grade that a car will ascend, when a fraction of its weight is on the drivers, is equal to that fractional part of 2,000 times the ratio of adhesive force to weight on drivers minus 25, this difference being divided by 20.

EXAMPLE.—The limit of adhesion being $\frac{1}{6}$ the weight on the drivers, how steep a grade could be surmounted by a car with $\frac{1}{4}$ its weight on the drivers, starting from the level?

SOLUTION.—According to formula 6,

$$G_r = \frac{\frac{2{,}000\,a}{y} - 25}{20} = \frac{\left(\frac{2{,}000}{4} \times \frac{1}{6}\right) - 25}{20} = 2.91 \text{ per cent. Ans.}$$

40. The foregoing data and formulas will enable approximate calculations to be made regarding the power required for a given number of cars. It is unsafe to give values of the power to be allowed per car, because there is such a wide variation in the size and weight of cars that such figures are not generally applicable. The safest method is to calculate the power required for any given case by taking into account the weight of the cars, speed, steepness of grades, etc., as indicated in the above formulas.

THE LINE.

41. The term **line**, when used in connection with a street railway, covers quite a large field of work; in the first place, the line may be an overhead-trolley system, a conduit system, a third-rail system, or a high-potential transmission line. Also, the name can include any of the several sectional surface systems, none of which, however, are in general enough use to warrant its consideration here. Whatever the system may be, its consideration calls for a study of the active trolley wire, its feeders, and their means of support.

OVERHEAD LINE CONSTRUCTION.

42. General Features.—When **overhead construction** is spoken of, it is generally understood to refer to the common overhead-trolley system that is used wherever it is permitted, because it is so much cheaper than any of the other systems. Overhead construction includes the setting of the poles, the stringing of the feed wires and the trolley wire, with its span wires, guard wires, anchor wires, insulating hangers, coupling devices, switches, etc. The feed wires, or feeders, i. e., the wires communicating directly between the generators at the station and the several points of distribution, are carried overhead or are laid underground if necessary. When the feeders are carried overhead, it is the rule to support them on cross-arms from the same poles that support the span wires and trolley. Sometimes, however, if the feeder followed the line of the track, it would be unnecessarily long. In such a case, its route would lay across country or across town, as the case might be.

43. In Fig. 16, *P* is the site of the power house; *k–a–CB–b–e* is the trolley wire, which of course has to follow the track. The trolley wire is divided into two sections, *a* and *b*, separated by the circuit-breaker *CB*; the term circuit-breaker used in connection with line work denotes a fitting for putting a break, or insulating joint, in the trolley line. Each section of the wire is fed by its own feeder. Feeder b_1 feeds into section *a* at *a* and follows the line of the track up to that point. Feeder b_2 feeds into section *b* at *b*, but instead of following the track and taking the long path around, as shown by the dotted line, it cuts across, as shown by the full line, thus effecting a great saving in length. It is, as a rule, cheaper in such cases to take the short cut, even if a pole line has to be erected just for the feeder, because great length in a feeder not only means a

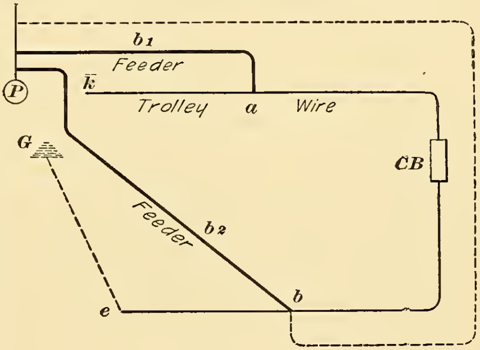


FIG. 16.

great outlay in copper, but it also means that the additional resistance helps to defeat the purpose of the feeder—that of keeping the voltage up to a practicable value on the line.

44. Most overhead-trolley systems use a **rail return**; that is, the current leaves the power house by way of the feeders and perhaps the trolley wire, passes through the car motors and returns to the power house by way of the rails, the earth, and whatever water, gas, or other pipes may happen to parallel the track. The return circuit, then, is an item of just as much importance, as far as conductivity is concerned, as is the overhead work, and in some cases it is of more importance, because when the rail return is bad, so much current follows the path of neighboring pipes as to injure them and bring on lawsuits.

A glance at Fig. 16 will show that although feeder b_2 allows the current a short path from the power house to the point of distribution b, it does not provide a short path back to the power house. To reach the power house, the return current must follow the rail, and it would be very easy under such conditions for a greater drop to take place in the track return than in the overhead feeder. It is easily seen that, if a ground wire were run from some point on the rail in the neighborhood of b, or even from the end e to the ground bus-bar at the power station, it would greatly improve the conditions of the service.

Should it be found desirable or should circumstances make it necessary to put the feeders underground, they should be handled with great care and should be substantially protected from any liability to abrasion, since faults are somewhat difficult to locate and expensive to remedy. The feeders, as a rule, are encased in a lead sheathing, which not only is a protection against abrasion and moisture, but leaves the feeder pliable and easy to handle. A break in the sheathing due to a bruise or a kink may not cause any trouble for months after the feeder has been in active service, but in course of time moisture will work through and establish conditions for setting up a leakage current, which will gradually convert the fault into a short circuit. Even in stringing feeders overhead on iron poles, a little carelessness on the part of the linemen will give rise to the same trouble. The ordinary practice in stringing such feeders is to set the reel upon which the feeder wire is wound near the first pole and on the off side; one end of the wire is then passed over the cross-arm of the pole and a horse or car is hitched to it to pull it to the next pole, over the cross-arm of which it is also raised and the operations continued until the wire is in place. If there happens to be a snag on the cross-arm or if the feeder gets caught, a hole is cut in its insulation. If, after the feeder is secured in place on its insulators, the injured part falls between poles, it can do no harm, unless a telephone or light wire happens to fall across it at some time; but if, as often happens, the abraded part falls over the cross-arm, then the first time a heavy wind lifts the feeder off the insulator and lets it down on the iron cross-arm, trouble begins.

FEEDERS.

45. The whole distributing system of an electric railway may be generally divided into two parts—the **feeders** and the **working conductor.** The latter usually takes the form of a trolley wire in overhead work, but it may be a third rail or the conductor rail in a conduit system. The feeders are usually in the form of heavy cables run out from the station to supply different sections of the working conductor. Feeders may be run overhead or underground. In small towns and cities or on cross-country roads, they are run on poles, because this is the cheapest construction. In large cities, however, they are run underground. City ordinances often prohibit running them overhead on account of their unsightliness and also on account of their being a nuisance and source of danger in case of fires. Underground construction is expensive, but it has its advantages. Electric-railway companies objected very strongly when they were first required to put their feeders underground, but many of them are now strongly in favor of it. Underground wires are not disabled by snow and sleet storms, and on the whole their service is more reliable than that of overhead wires.

Where feeders are run underground, they are usually in the form of lead-covered cables. These are pulled into ducts, and manholes are provided at intervals to allow access to the cables for making repairs and locating faults.

46. General Methods of Feeding.—The simplest method of line construction is to use a single wire, serving both the purpose of trolley wire and feeder; but with a heavy load, the drop of potential at the end of the line, except in special cases, would be too great if the trolley wire alone were used. It is more satisfactory to run a heavy cable alongside of the trolley wire and tap it into the wire at intervals along the route: the two together will carry the load with much less loss in voltage than will the trolley wire alone. Such a plan is shown in Fig. 17, where *m n* is the trolley wire, *a b* the feeder, and *f*, *f* the several taps. The power station is supposed to be at one end of the line at *S*. It would be a much more economical arrangement were the power station in the center, as shown in Fig. 18, so that it might feed in both directions and thereby halve the distance from the power house to either end of the line.

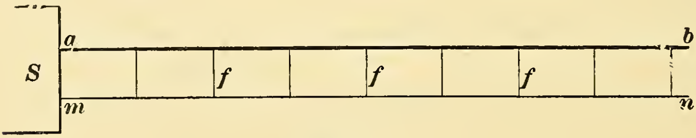


FIG. 17.

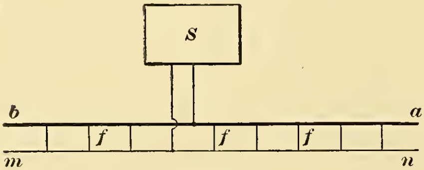


FIG. 18.

If the trolley wire is divided into a number of sections *c*, *d*, *e*, *f*, *g*, each connected at its center to the feeder *a b*, as shown in Fig. 19, the drop in potential at any point would be due only to the feeder and that portion of the trolley line between the point in question and the tap line. In case

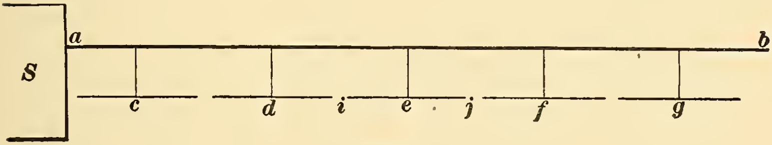


FIG. 19.

of a fire at any place along the route or in case of a ground on a bridge or in a tunnel, the power could be shut off in that district without disturbing the other parts of the line, so that the whole road would not be shut down. In order to do this, each tap wire should be provided with a switch that is mounted on the pole at the point of connection to the feeder. Fig. 20 shows a line switch for this purpose. It is mounted on the pole and the lower terminal is connected to the trolley. When the switch is opened, the blade can be thrown all the way down and the door closed. All the exposed parts are then dead and the switch cannot be closed until the door is unlocked. The several sections of the trolley wire are well insulated from one another by line circuit-breakers, or section insulators, which will be described later.

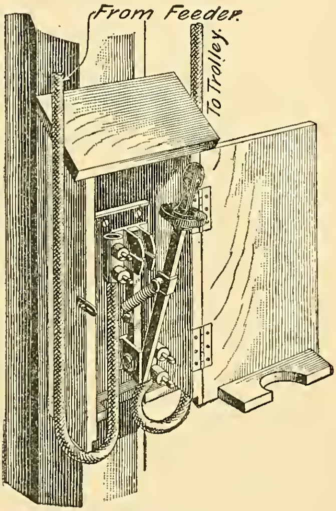


FIG. 20.

47. Fig. 21 is a plan of feeder wiring that approaches more nearly the trend of present practice than any of the other plans so far shown. It approaches the condition where the trolley wire is divided up into several sections, each of which is provided with its own feeder. But in the case shown in Fig. 21, each feeder supplies several sections of trolley wire by means of extension feeders or

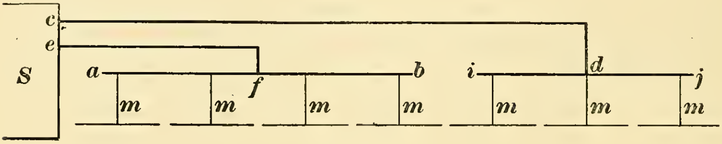


FIG. 21.

mains *a f*, *f b* on the end of the main feeder and an independent tap running to each section of trolley.

Fig. 22 shows the best plan for a feeder service. In this case, each trolley section has a feeder of its own. Of course, the feeder is tapped into its section in as many places as may be deemed advisable. Each feeder and its section of

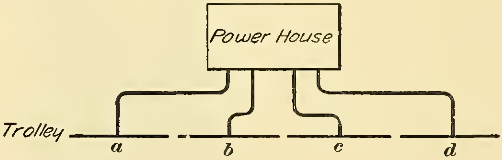


FIG. 22.

trolley wire may be looked on as a single unit, and the idea can be extended to any system, however large. Such a plan not only simplifies calculations, but limits the field for troubles as well. Any trolley section may be cut out by means of its feeder switch.

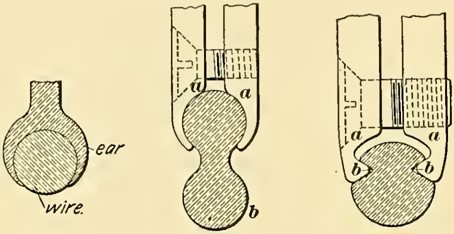
48. Overhead feeders are usually in the form of heavy stranded cables covered with weather-proof braided insulation. If a very large feeder is not required, solid wire may be used or two or more wires may be run in multiple to make up the requisite cross-section. The accompanying table gives the make-up of triple-braided weather-proof railway feeder cables as made by the American Electrical Works.

Size.	Style of Conductor.	Approximate Weight per Mile. Pounds.
1,000,000 C. M.	61 wires, .128 each.	19,000
950,000 C. M.	61 wires, .125 each.	18,250
900,000 C. M.	61 wires, .122 each.	17,280
850,000 C. M.	61 wires, .118 each.	16,320
800,000 C. M.	61 wires, .115 each.	15,360
750,000 C. M.	61 wires, .111 each.	14,400
700,000 C. M.	61 wires, .107 each.	13,450
650,000 C. M.	61 wires, .103 each.	12,480
600,000 C. M.	61 wires, .099 each.	11,600
550,000 C. M.	61 wires, .091 each.	10,560
500,000 C. M.	49 wires, .101 each.	9,800
450,000 C. M.	49 wires, .096 each.	8,600
400,000 C. M.	49 wires, .090 each.	7,500
350,000 C. M.	49 wires, .085 each.	6,500
300,000 C. M.	49 wires, .078 each.	5,500
250,000 C. M.	49 wires, .071 each.	4,860

TROLLEY WIRE.

49. In the early days of electric railways, the trolley wire was much smaller than that now used. No. 2, 3, or 4 B. & S. soft copper wire was used in many cases, but it was soon found that this wire was not strong enough mechanically. Hard-drawn copper wire is now used in most cases, and the size is generally from No. 0 to No. 000; in some cases, No. 0000 wire is used. Wire smaller than No. 0 should not be used. Hard-drawn copper wire has a little higher resistance than soft-annealed wire, but its tensile strength is very much greater; hence its use for trolley wire. Where a very strong wire is required, phosphor-bronze is sometimes used.

50. Shape of Trolley Wire.—Trolley wire is nearly always round in cross-section. This answers for ordinary work in towns and cities where the speed is not high. Fig. 23 (*a*) shows the ordinary round wire held by a soldered ear. The ear is tapered down to an edge, so that it will allow the under-running trolley wheel to pass as smoothly as possible. Even if the fins on the ear are thin, there is always more or less of a jump when the wheel passes under the hanger, and this gives rise to trouble if the car runs at high speed. The sparking caused by the jump also eats the hanger away and causes breakage in course of time. The jump is even more pronounced if ears which clamp the wire, instead of being soldered, are used. Clamping ears project more than soldered ones, and hence there is more of a knock when the wheel passes under them.



(*a*) (*b*) (*c*)

Fig. 23.

For cross-country or interurban roads, where high speed is attained, it is very desirable to have the trolley wire so suspended that it will offer a smooth running surface for the trolley. Fig. 23 (*b*) shows a wire designed to accomplish this. It is the shape of a figure 8 in cross-section and the upper part is gripped by the clamp ears *a*, *a*, the lower part *b* being free from obstruction. The objection to this style of wire is that if it becomes twisted between supports, so that it lies crosswise, the wheel does not run well.

Fig. 23 (*c*) shows another style of wire introduced by the General Electric Company. This wire is also supported by clamp ears *a*, *a*, and the surface presented to the trolley wheel is smooth. The wire is practically circular in cross-section, with the exception of the two grooves *b*, *b* in the side, so that if the wire twists between supports it does not interfere perceptibly with the smooth running of the wheel when high speeds are attained. Fig. 24 shows clearly the method of supporting this wire.

When soldered ears are used, the obstruction offered is so slight that a round wire answers in the great majority of cases. When clamped ears, however, are desired, and when high speeds are developed, these special shaped trolley wires will be found advantageous.

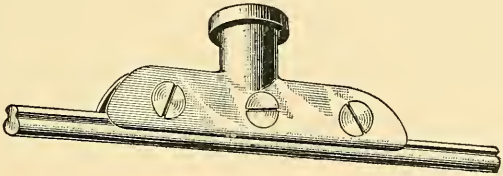


FIG. 24.

METHODS OF ARRANGING TROLLEY WIRE.

51. There are three styles of support for trolley wires: they may be suspended directly from brackets on poles at the side of the road; or a double track may be provided with center poles carrying the wires on a projecting arm on either side; or the poles may be placed at the sides of the street and the trolley wire supported by span wires stretched across.

52. Span-Wire Construction.—This is the most common method of suspension, and it is preferred for the following reasons: In the first place, it does not obstruct the center of the roadway as the center-pole construction does; in the second place, there are places where only one side of the road can be used, as on country roads, where passages for two teams must be left outside of the track. Again, where a single track is laid with the prospect in view of making it a double track if the traffic warrants doing so, the side-pole, span-wire construction leaves very little additional work to be done when the time comes for doubling the track. In such a case, it is often the practice to string two trolley wires alongside of each other about 8 inches apart. As long as the road is a single-track road, the cars use one wire going one way and the other wire coming back; this saves overhead special work at turnouts and saves copper in the feed wires. When the time comes for doubling the track, it is only necessary to slide one wire over into place and see to its insulation from the ground. In such straightaway construction, it may be that no feeders are used, in which case the road cannot be divided into sections, but the two wires must be continuous from the power house to the end of the line.

In Fig. 25, *a b* is one trolley wire and *c d* is the other; *T* is a turnout—a switch where cars can pass each other, and the other dotted line *e f* shows the position of the wire *a b* after it has been moved over to the second track. It is easy to see that the parallel construction does away with the necessity of any overhead special work at the turnouts. If all the turnouts are placed on the same side of the track, it leaves one wire straight.

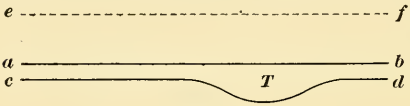


FIG. 25.

One rather unusual condition, under which the side-pole, span-wire method has a decided advantage, is where a projected road has trouble in obtaining right of way through the country. One owner may give the right of way in front of his property, but the owner across the road may refuse it, so that the track will have to be laid on one side of the neutral line. It may be necessary to do this several times in the course of a few miles, with the result that the line zigzags from one side of the road to the other. If the center-pole construction is used, the poles will have to zigzag with the track; but if side poles are employed, it will be necessary to make only the trolley wire itself conform to the serpentine track construction by sliding the wire one way or the other on the span wire. In course of time, if the track can be straightened, the only change necessary in the overhead construction is to move over the trolley wire.

53. Fig. 26 shows the general arrangement of a span-wire suspension. In this case iron poles are shown, so that an insulating turnbuckle is used between the pole and the span wire. The trolley hanger is also insulated, so that there is high insulation between the trolley wire and the ground even though iron poles are used. The feeders are carried on cross-arms bolted to the poles. Where wooden poles are used, the insulated turnbuckles are often omitted. An eyebolt is simply passed through the pole and the span wire is stretched by screwing up a nut.

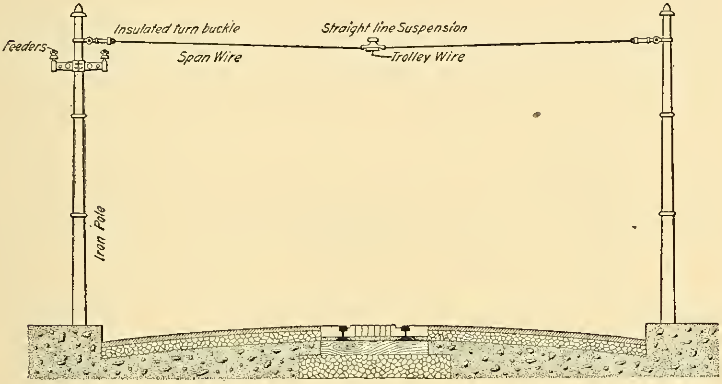


FIG. 26.

54. Center-Pole Construction.—Center-pole construction can be used to good advantage on very wide streets, where the poles will not be in the way. If ornamental center poles are used, the general appearance may be made very pleasing. Sometimes arc lamps are mounted on every other pole, thus adding to the general effect at night. Where ornamental construction is used, the unsightly feeders are generally run underground, but if this is impracticable or if it is undesirable to run the avenue feeders in a conduit, the same effect can be obtained by running the feeders overhead, but up a street that parallels the main avenue. In this case, the taps must run from the feeder in the side street to the trolley wire. This feed tap disappears into the ground just off the avenue and does not show again except where it is spliced to the trolley wire. From the side street to the pole it is carried in a tube; it then passes up through the center of the pole to the bracket and out to the wire.

55. Side-Bracket Construction.—When this construction is used, the track is generally on one side of the street. It is used most extensively for cross-country lines where a single track runs along one side of the road. For this class of work, cheap gas-pipe brackets are generally used, and since the construction calls for only one pole, whereas a span wire requires two, it is inexpensive.

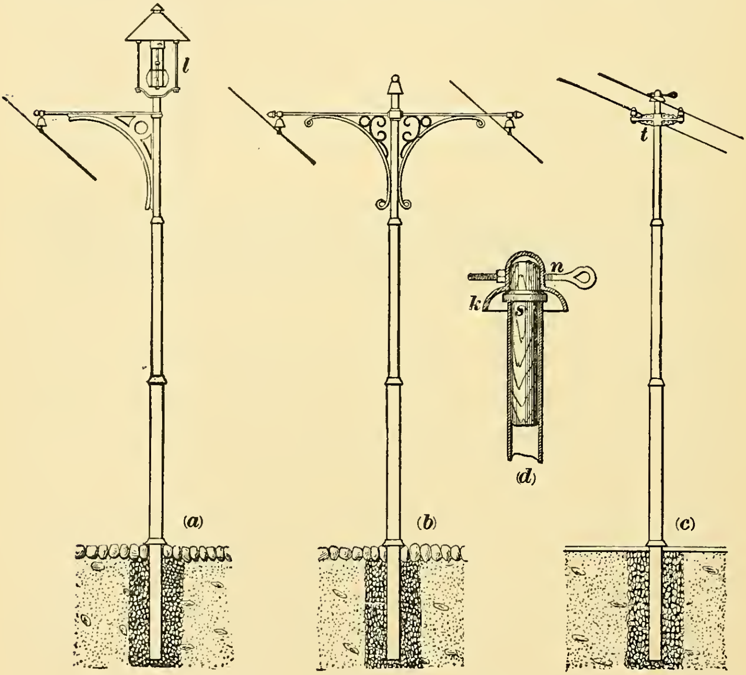


FIG. 27.

56. Steel and Wood Poles.—At the present time, the poles used are either steel or wood. For cross-country or suburban roads, wooden poles are as a rule selected, because appearances are not so much a matter of consequence, and they are even used in city streets where no very strong objection is made to them. Steel poles are, however, much the better for city streets. There are a great many tubular steel poles of the telescope type in use in cities; in fact, many cities will not allow the use of wooden poles on the ground that they are unsightly. Seamless steel-tube poles are also coming much into favor, as they are strong and last a long time. Such poles are invariably set in concrete.

57. Tubular Steel Poles.—Fig. 27 shows a tubular pole adapted to the various types of construction; (*a*) is the side bracket, (*b*) the center pole, and (*c*) the plain pole for span-wire construction. The poles are about 30 feet long, the lower section being 6 or 8 inches in diameter and the others 1 inch smaller successively, fitting inside of each other with telescope joints that ought to be at least 18 inches long. Fig. 27 (*d*) is an enlarged view of the top of the pole shown in (*c*) without a bracket. It shows the insulated top *k* supported on a wooden block *s* and carrying the tension bolt *n*, to which the span wire is secured through the medium of an insulator. The cross-arm *t* carries feeders to supply current at distant points. The pole may also be utilized to carry an arc lamp shown at *l* in (*a*). Instead of a tension bolt, there may be placed on the top of the pole, as shown at *a*, Fig. 28, a ratchet provided with a counter-balanced pawl *b*, engaging with the teeth. The base *c* has flaring sides to shed rain and fits into the insulating wooden block *d*. In a slightly modified form, the ratchet may be fastened to the side of the pole

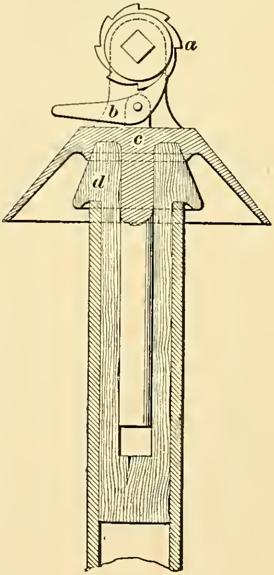


FIG. 28.

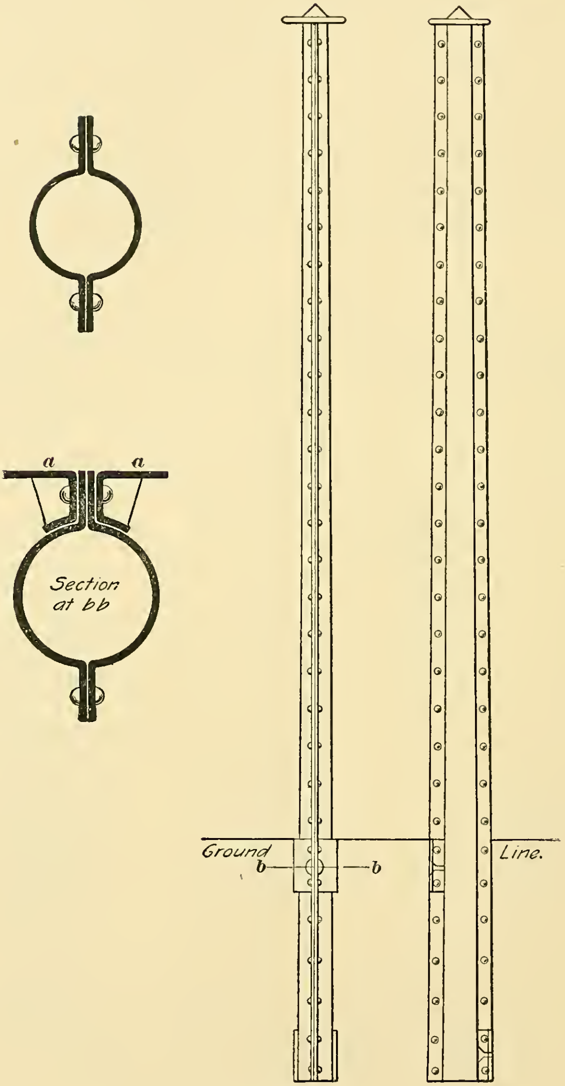


FIG. 29.

at any point or bolted to a wooden pole. In addition to these arrangements, a clamp may be used on the pole in connection with a turnbuckle, as shown in Fig. 26.

58. Structural-Steel Poles.—Steel poles are sometimes made in other than telescope tubular form. Fig. 29 shows a pole made of pressed steel halves riveted together. Pieces *a*, *a* are riveted on at the bottom and at the ground level, so that the pole will have a flat surface of considerable area to enable it to better withstand the strain due to the span wire.

Latticework poles are also largely used; they are neat and strong and can be painted inside and out. They are also easy to climb.

59. In both bracket and center-pole construction, it is now the practice to use a flexible support for the trolley-wire hanger, to prevent the destructive blow of the passing trolley wheel and reduce the sparking. Such an arrangement is shown in Fig. 30, which represents a form used for the side-bracket construction. A span wire *w* holding the hanger *h* is stretched tightly between two insulators *i*, *i'*; the outer one is secured to a bracket *b* and the inner one is held by a clamp on the framework. In the center-pole method of construction, the brackets extend on both sides, and when the pole is of wood, a hole may be bored through it to receive the span wire. Of course, in the ordinary side-pole, span-wire method of construction, no such device is needed to cushion the blow of a passing trolley, as this trouble is looked after by the natural flexibility of the suspension.

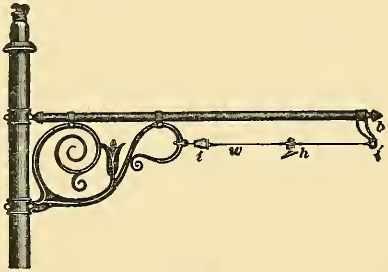


FIG. 30.

60. Wooden Poles.—For ordinary use, the diameter of the base of a wooden pole should not be less than 10 inches, tapering to 6 or 7 inches at the top, which should be cut to a conical shape so as to shed water. The pole from the ground up may be round or octagonal. Octagonal poles look better, but poles naturally round last longer. It will be found to prolong the life of a wooden pole and also lessen the liability to current leakage if the part above the ground is covered with two coats of paint. The part that is to be under the ground should receive a preservative of some sort, such as tar.

61. Setting Iron Poles.—The lower end of the pole is sunk in the ground 6 or 7 feet and filled around with cement and broken stone. The amount of concrete to be used at the base of each pole cannot be laid down as a general rule, because it varies according to the soil encountered. In some places it is necessary to blast the holes for the poles in the solid rock ; in such a case only enough concrete need be used to give the pole a firm set. In other localities there may be no rock and yet the subsoil may have plenty of body, in which case the hole may be made about the diameter of an oil barrel and the space surrounding the pole filled in with concrete. The concrete is used to increase the surface on which the lateral pressure at the base of the pole acts. It must be borne in mind that the span wires are strung under considerable tension and that they tend to pull together the tops of the tube poles to which they are connected, and the poles will yield unless they are firmly fixed in the ground. The concrete sticks to the pole base as if it were a part of it, and in this way increases the diameter of the base and enables the pole to resist any effort to pull it over. Some soils are so very giving in nature that it is necessary to dig a hole several feet in diameter around the pole ; the pole is then set in concrete and the rest of the hole is tamped full of stones, broken brick, etc.

62. Guy Wires and Slanting of Poles.—Sometimes even the above treatment does not secure a setting that can be relied on, so it is supplemented by a guy wire that puts a strain on the pole opposite to that exerted by the span wire. These guy wires are most often called for on corner poles that support feed wires turning at that point. To offset the tendency of the span wires to pull the tops of the poles together, the poles are all canted outwards, about 6 inches out of plumb. In some cases even more slant than this is needed. Too much stress cannot be laid on the importance of setting the poles properly and doing the work so that they will stay so ; for when a pole gives to the tension of the span wire, it makes a zigzag in the trolley wire, which is rigidly attached to the span wire through the medium of its insulator. As soon as the wire gets out of line the never-ending trouble of the car trolley pole jumping the wire begins. When the pole flies off at one span wire, it generally manages to strike the next one or two, and the trouble goes from bad to worse.

63. Setting Wooden Poles.—Wooden poles are not, as a rule, set with concrete, although there is no good reason why they should not be. When the side-pole, span-wire construction is used, the wooden poles should have their earth bearing increased by the proper disposal of several large stones. A couple of stones should be jammed into the hole alongside of the pole on the side away from the track and a couple more near the mouth of the hole on the side next the track. This will do a geat deal towards preventing the span wire from pulling the tops of the poles together. A piece of timber may be substituted for the stones on the track side, and in such a case should be about 3 feet long and 8 inches in cross-section. The outward slant of a wooden pole should be about twice that of a steel pole in the same soil, and when in position, the pole should be solidly tamped around to make a firm bed. The tamping should be done while the pole is free; if done while there is tension on the span wire, the effect will be just the opposite to that desired.

The selection of wooden poles for an extensive system should be left to a man thoroughly familiar with the work. The buying of metal poles is not such a risky undertaking, because they can be bought under guarantee to fill certain specifications, but almost any one not long identified with the business is liable to make mistakes in selecting wooden poles.

ELECTRIC RAILWAYS.

(PART 3.)

LINE FITTINGS AND LINE ERECTION.

THE TROLLEY WIRE.

1. The general arrangement of wiring for a double track is shown in Fig. 1. The poles *p* are placed not more than 125 feet apart measured along the road, and between opposite poles are stretched the **span wires** *s*. At intervals of about 500 feet and at the approach to all curves, **anchor wires** *a* are put up, being secured by special hangers, as at *h*. Anchor wires take up the strain on the trolley wire in the direction of its length, for it must be borne in mind that the trolley wire is put up under considerable tension, so that should it break it would draw apart in both directions if there were no anchor wires to hold it in position. The two general methods of stringing the trolley wire depend on whether it is put up dead or alive, i. e., whether the current is off or on. In the first case, the wire is run off the reel

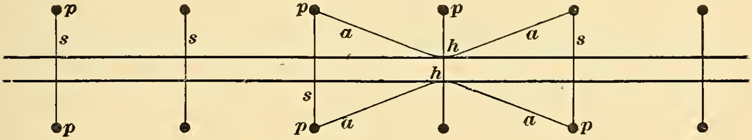


FIG. 1.

under the span wires and is then raised and tied temporarily to them; the tension is put on afterwards and the wire fastened to the insulators.

If the wire is put up alive, the reel is put on a flat car that is moved by a trolley car. As fast as the wire is paid off, it is fastened to the insulators, once for all, by a line crew that follows close behind. It may be necessary to go over the road afterwards and make a final adjustment, especially at curves and crossings.

2. Erection at Curves.—The method of securing the trolley wire at curves is shown in Fig. 2, where *A* represents the arrangement of guy wires *g* attached to the trolley wire *t* when a single pole is used. Strain insulators are usually

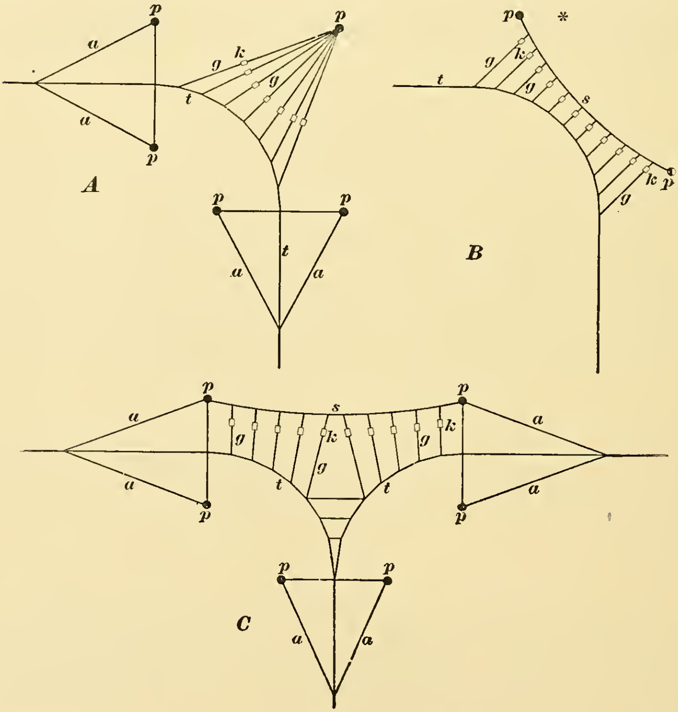


FIG. 2.

inserted as shown at *k*, and the trolley wire, at the beginning of the tangent or straight portion, is held by anchor wires *a*. A flexible method of suspension is shown in diagram *B*, where a heavy span wire *s* holds up the guy wires; this form of construction tends to equalize the strains on the span wires, and is generally adopted in place of *A*, which is the older method. A double curve is shown at *C*, the different wires and poles being designated by the same letters as in the preceding layouts.

3. Offset in Trolley Wire.—In going around a curve, the trolley wire does not follow the center line between the rails as it would do if the trolley wheel were applied to the wire at a point immediately over the center of the car, but it is strung over towards the inside rail by a distance that depends on the radius of the curve. This departure from the center line of the track is shown in Fig. 3, where the curve *r* is the center line of the rails and *t* the path of the trolley wire. The amount of offset measured at the middle of a 90° curve at the point indicated by the arrows in the figure should be about as follows:

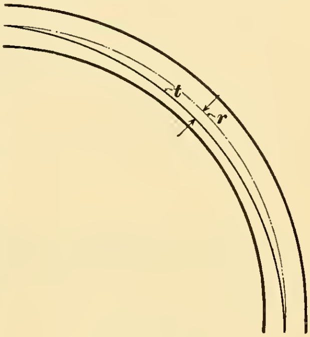


FIG. 3.

Radius of Curve in Feet.	Offset.
40	16 inches.
50	13 inches.
60	12 inches.
80	8 inches.
100	6 inches.
120	5 inches.
150	4 inches.
200	3 inches.

The object of the offset is to allow the trolley wheel to lie more closely to the wire; it would not do this so well if the wire followed the center line of the track, as the wheel would lie diagonally across the wire and cause a large amount of wear on curves. Evidence of this can be seen on many old lines.

4. In some places **guard wires** are required above the trolley wires. These are strung about as shown in Fig. 4, being about 18 inches above and to one side of the trolley wire. The object in using guard wires is to prevent telephone or other wires from falling across the trolley wire. Guard wires are not used as much as they once were; they are usually of No. 6 or 8 B. W. G. galvanized-iron wire.

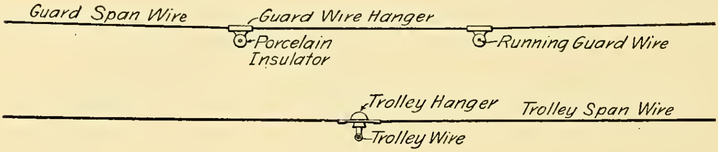


FIG. 4.

Span wires used to support the trolley-wire suspensions should be about No. 1 B. & S. steel wire, if No. 0 trolley wire is used, and should be well galvanized. The trolley wire should hang about 19 feet above the rail. Of course, there are places where this rule cannot be adhered to, for at steam crossings the wire must be higher than 19 feet and under elevated structures it must be much lower. The insulation must be as good as possible, not only to avoid current leakage itself, but also its direct effect, i. e., live poles.

5. Insulators are used in two places—at or near the pole and again at the trolley-wire hanger. Those in the span wire are called **strain insulators,** because they have to stand the tension or strain on the span wire. Fig. 5 shows a simple strain insulator. The span wires are attached to the two pieces *a*, *a* and the pull is taken up against piece *b*, which is separated from pieces *a*, *a* by insulating material. The whole insulator, with the exception of the two eyes, is covered with molded insulating material.

Fig. 6 shows a strain insulator and turnbuckle combined, the turnbuckle serving to stretch the span wire. In Fig. 6, i is a globe of hard molded insulating material. Into this ball, but not touching each other, are secured the eyebolt e and the straight bolt s; the turnbuckle p, which engages the bolts s and s', is fitted with right- and left-hand threads for regulating the tension, and the ends of the span wire are fastened to the device at e and e'. The turnbuckle is used not only for regulating the tension of the span wire, but also for correcting minor irregularities in the centering of the trolley wire by paying out on one turnbuckle and taking up the other. When a ratchet is used, no turnbuckle is needed and the insulator takes the simple form of an insulating ball or cylinder with an eyebolt in each end, as shown in Fig. 5.

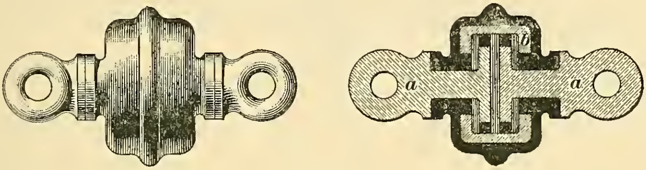


FIG. 5.

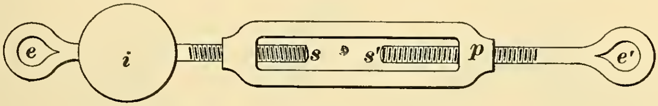


FIG. 6.

6. Trolley-Wire Suspensions.—The hangers for suspending the trolley wire are made in a great variety of designs, but in general they consist of three parts, namely, a casting of some kind that is held by the span wire or bracket, an ear that grips or is soldered to the trolley wire, and insulating material that separates the ear from the casting. Fig. 7 shows a common form of suspension with the ear removed; a is the main casting provided with the grooved extensions d. The span wire passes through d and around *a*, thus holding the hanger in place. The bolt *c* is bedded in molded insulating material and the casting is covered by a metal cap *b*. The ear to which the trolley wire is fastened screws on *c*.

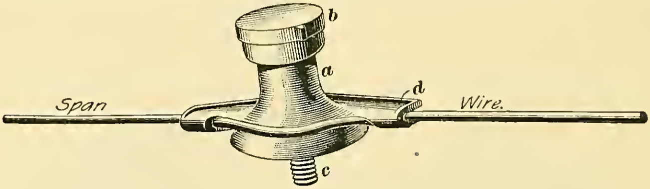


FIG. 7.

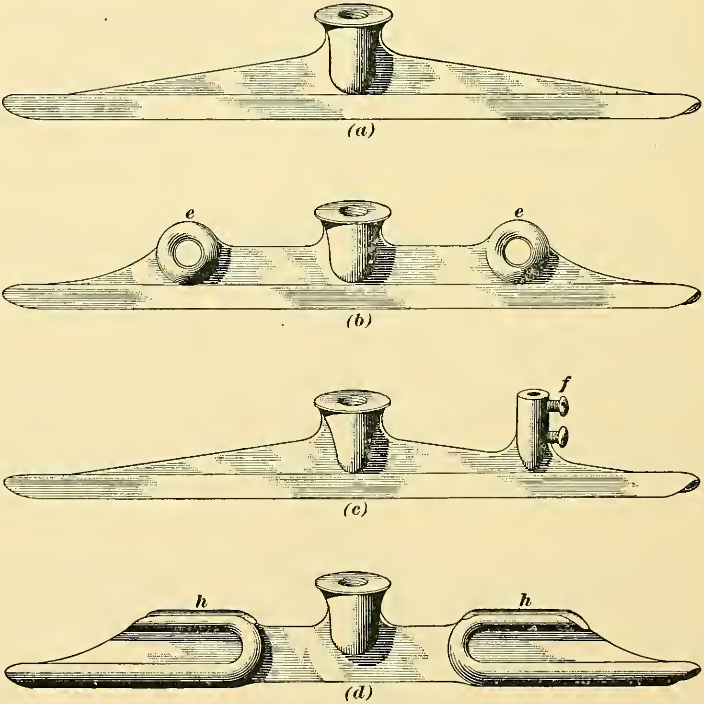


FIG. 8.

The metal castings for overhead fittings are made either of malleable iron or brass. The ears when soldered are made of brass; those designed to clamp on the wire are usually made of malleable iron.

Fig. 8 shows four styles of ears intended for soldering to the trolley wire. These ears are provided with a groove on the under side, in which the wire lies. The ear shown at (*a*) is known as a **plain ear**; it is used for ordinary straight-ahead work. (*b*) shows a **strain ear,** so called because it is provided with lugs *e*, *e*, to which the wires *a*, *a*, Fig. 1, are attached. (*c*) is a **feeder ear**; it is provided with a lug *f*, to which the tap from the feeder attaches. (*d*) is a **splicing ear,** used where the trolley wire comes to an end at a hanger. This ear serves the double purpose of holding the wire and acting as a splice. There are two openings *h*, *h* in the casting, and the ends of the trolley wire are passed up through these and bent back over.

7. Fig. 9 shows a suspension provided with an automatic ear. This ear is made in two parts that are hinged together. When *b* is screwed up, the ear *e* clamps the wire, thus holding it firmly without the use of solder. Automatic ears make more or less of a projection, and hence tend to make the trolley wheel jump more than soldered ears. They are, however, easy to put up and are especially useful in places where the location of the hangers may have to be changed.

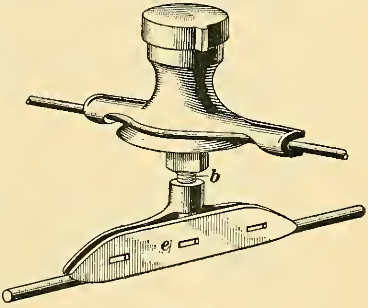


FIG. 9.

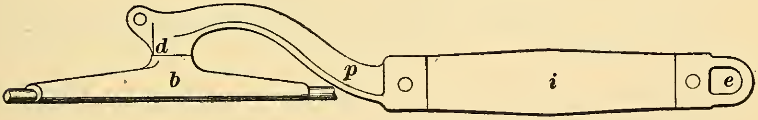


FIG. 10.

8. In rounding a curve, the trolley wire is at first stretched in temporary wire slings and anchored, after which the hangers or pull-over clamps are attached. For curves of small radius, a form of suspension such as is given in Fig. 10 may be used. The span wire is attached to the eye *e*, which is fastened by the insulating piece *i* to the arm *p* carrying the trolley-wire clamp *b* pivoted at *d*. For suspending trolley wires and making repairs on the same, a "tower wagon" is used, which consists of a platform supported on a wagon at a convenient height for ready access to the wires. This platform is generally so arranged as to project beyond

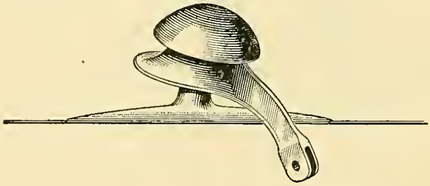


FIG. 11.

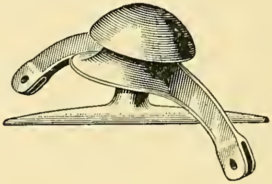
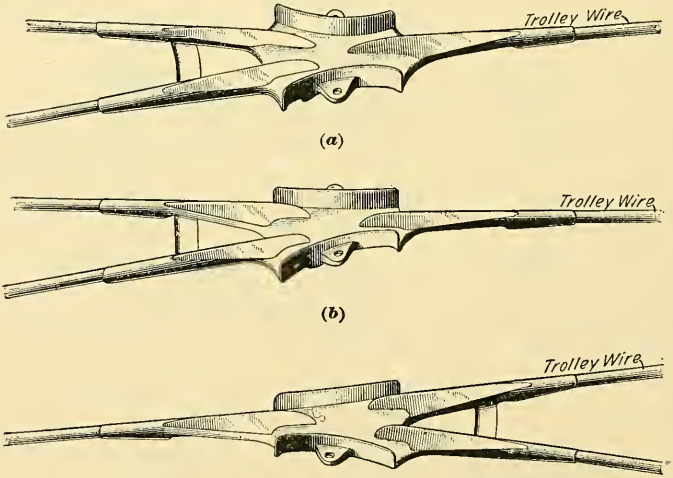


FIG. 12.



(*a*)

(*b*)

(*c*)

FIG. 13.

the wagon, so that the latter may stand clear of the tracks while repairs are in progress and not interfere with regular traffic. When not in use, the platform may be lowered to the wagon by means of a winch.

Fig. 11 shows a single-curve suspension or pull-off. Fig. 12 shows a double-curve suspension.

9. Branch Lines and Curves.—At the point where one line branches from another, overhead switches, or **frogs,** are used to guide the trolley wheel from one wire to the other. Fig. 13 (*a*) shows the under side of a simple two-way **V** frog of a type that is largely used. (*b*) is a right-hand frog and (*c*) a left-hand frog. In these frogs the trolley wire is soldered into the ears. Fig. 14 shows a **V** frog in its natural position. In this case, the trolley wire is held by clamps *b*, *b*, *b* and no solder is necessary. The span wire is attached to ears *a*.

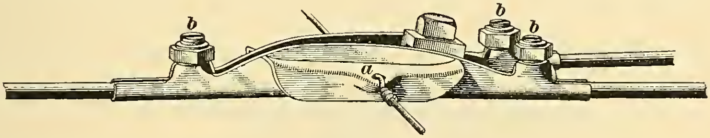


FIG. 14.

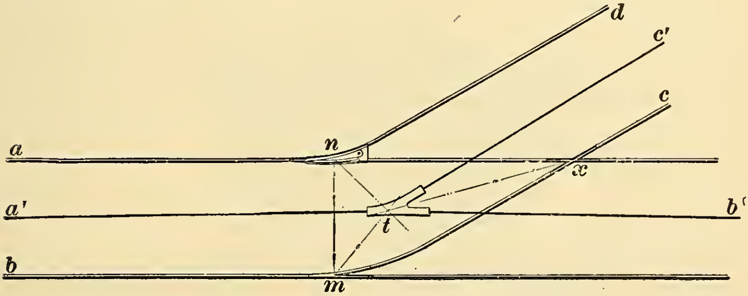


FIG. 15.

10. It is necessary that frogs be placed correctly with relation to the track, and mechanical fastenings for the wires are therefore desirable, because they allow the frog to be adjusted to the position giving the best results. The satisfaction that any frog will give depends a great deal on how it is put up. If put up level, the trolley is very likely to follow the same direction as the car, but if allowed to sag down on one side, it will be a never-ceasing source of trouble, due to its throwing the trolley wheel off the wire. The position for the frog may be found by the method shown in Fig. 15, where a and b are the main-line tracks, c and d the branch-line tracks, $a' b'$ the main trolley wire, and $t c'$ the branch trolley wire. The center of the triangle $n x m$ will be at a point t where the lines bisecting each angle meet, and this determines the position of the frog. It will be a little removed from the center lines of the tracks.

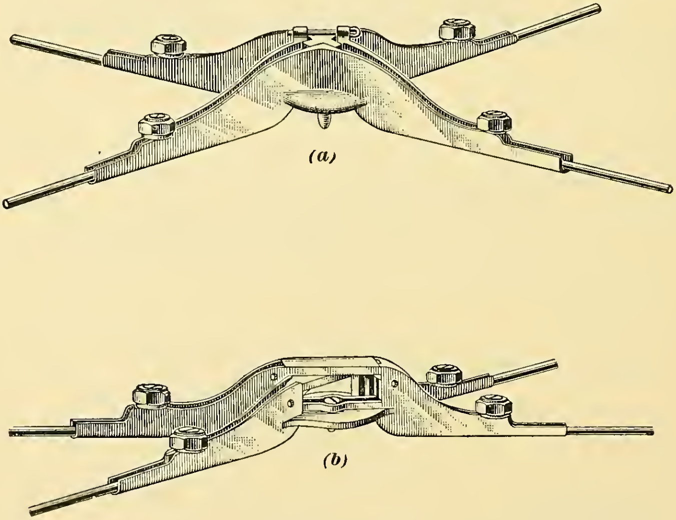


FIG. 16.

11. Cross-Overs.—At the point of intersection of two trolley lines, a device called a **cross-over** is used. Fig. 16 shows two common forms of cross-overs; (*a*) is used where the two lines cross at right angles, (*b*) where they cross at an acute angle. Where two lines meet at an angle that is only slightly oblique, it is very often the practice to offset one of the tracks just before the meeting point is reached, so that standard right-angled crossings can be used both in the line and in the track. Where the intersecting trolley wires belong to different companies, it is necessary to insulate the wires from each other. In such a case, a special insulating trolley crossing, Fig. 17, must be used.

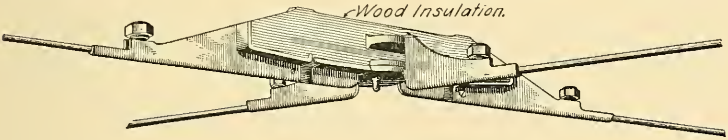


FIG. 17.

12. Section Insulators.—Section insulators are used at the junction of two divisions that are fed by separate feeders from the power house. These section insulators are commonly known as **line circuit-breakers** or simply **line breakers.** One form of line breaker is shown in Fig. 18.

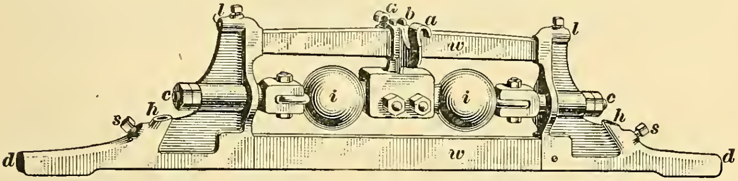


FIG. 18.

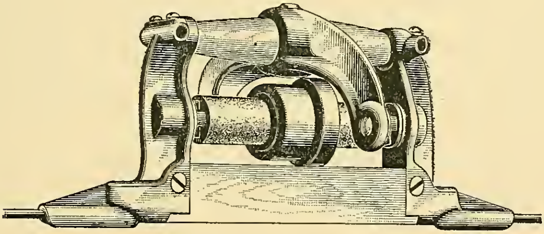


FIG. 19.

The direct line of the trolley wire is unbroken, allowing the trolley wheel to run smoothly across the insulator. The span wire is in one piece between the poles, and is slipped under the hooks *a*, *a* and over the notch at *b*. A double strain insulator *i*, *i* and bolts *c*, *c* hold the parts together against the pull of the trolley wires from the two sections which pass under the clips *d*, *d* at each end, through the holes *h*, *h*, and are held by the setscrews *s*, *s*. The end castings are provided with lugs *l*, *l* and setscrews, by which connection may be made to the feeders. Distance pieces of wood, well filled to prevent absorption of moisture, are inserted at *w*. Figs. 19 and 20 show two other styles of section insulators or line breakers that have proved satisfactory.

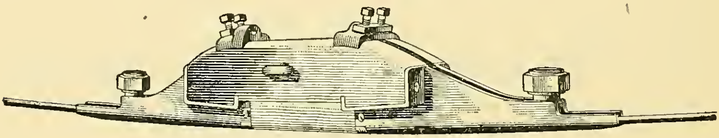


FIG. 20.

13. The main requirements for line devices of any kind are simplicity, durability, and strength. There is no place on the road where appliances are subjected to as violent knocks as they are on the line when struck by a pole that flies off under a tension of 20 or 25 pounds with the car going 20 or 30 miles an hour. Where the device has an insulator, this must be effective; for while the leakage current over one may be small, hundreds of them in multiple will amount to considerable. Every line should be subjected to a constant and careful inspection, and as soon as a fault begins to assert itself, it should be remedied at once.

14. **Wire Splicing.**—The feeders, if they are not in the form of large cables, are usually joined by using the ordinary Western Union joint, Fig. 21. A solution of rosin in alcohol makes a good flux for soldering such joints, as it does not corrode the wire. Large feeder cables may be joined either by weaving

FIG. 21.

the strands together and soldering or else by using a copper sleeve and thoroughly soldering it on the cable ends. Another recent and effective method of joining cables is to slip a heavy copper sleeve over the joint and then subject this sleeve to very heavy pressure by means of a special portable hydraulic press. All overhead wires after being spliced should be thoroughly taped, so as to provide an insulation at least equal to the covering on the wire.

15. Splicing Trolley Wires.—When a trolley wire is spliced, the joint has to be mechanically strong, because there is considerable strain on the wire; also, the joint must be made to offer as little obstruction as possible to the passage of the trolley wheel. This last requirement, of course, precludes the use of the style of joint shown in Fig. 21. One of the most common methods of splicing trolley wire is by means of a tapered brass sleeve, Fig. 22. The wires go in at each end of the connector and are bent up through the openings *a*, *a*. The remaining space is then poured full of melted solder and the ends of the wire trimmed off. This connector has given good service. The splicing ear shown previously in Fig. 8 (*d*) represents another method of splicing trolley wire. The general idea is the same as that used in the tubular trolley connector, except that it must be used at a point of support as indicated by the lug for attaching to the hanger. The ends of the wire to be spliced go into the ear at the ends, pass up through the holes *h*, *h*, and are turned back and trimmed off. The fins on the lower edge of the ear are clinched and the whole is then sweated with solder and cleaned off. Splicing ears do not always call for the use of solder; in some of them the wire is held by means of screw clamps.

FIG. 22.

Another style of joint, known as the **scarf joint**, is shown in Fig. 23. It should be at least 6 inches long. It is made by scarfing the ends of the two wires to be spliced until the two, when laid in lap, are the same size as a single wire. The ends are well cleaned and are laid together and wrapped with tinned binding wire. The whole length of the joint is then filled in with solder, the ends of the trolley wire being held firmly during the process by means of a screw clamp.

FIG. 23.

16. Feeder Insulators.—Heavy glass insulators similar to those previously described may be used for supporting feeders of ordinary size. In the case of large feeders, however, the strain is very great and glass insulators are liable to crack. This is especially the case at curves, where the strain on the insulator may be very heavy.

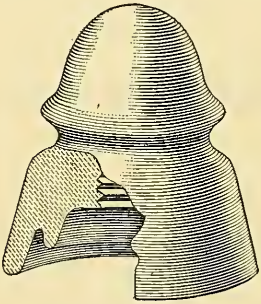


FIG. 24.

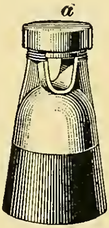


FIG. 25.

FIG. 26.

Where the heavy feeder cable subjects the pole insulator to a side strain, as at corners and curves, insulators of composition material, such as molded mica, are used, because this material is tougher than glass and does not crack under the strain. Fig. 24 shows one of these insulators having a groove large enough to take a cable up to 500,000 circular mils cross-section. Fig. 25 shows another style of heavy feeder insulator, the top of which is made of bronze and the lower part of molded insulation. The feeder rests in the groove and is held in place by the screw cap *a*. Fig. 26 shows still another style, in which the cable also rests in a groove on top, but is held in position by means of a tie-wire.

17. Connecting Feeders to Trolley Wire.—Fig. 27 shows one method of tapping the feeder to the trolley wire. In this case, a hard-drawn copper span wire is attached to

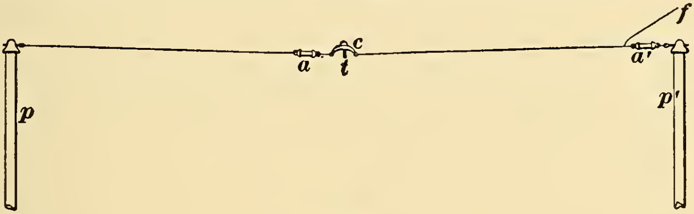


FIG. 27.

a non-insulating hanger *c* that carries the trolley wire *t*. At one end of the span wire, a tap *f* connecting to the feeder is joined on. Strain insulators *a*, *a'* are introduced, as shown, in order to insulate the live parts from the poles.

Fig. 28 shows a second and perhaps a better way of attaching the feeder to the trolley wire. The regular steel span wire is used to support the trolley wire by means of the hangers *e*, *e'*; supported on the same pole, but above

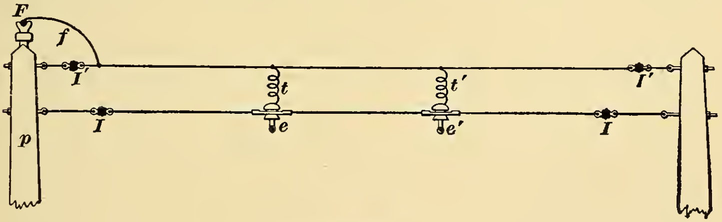


FIG. 28.

the trolley span wire, is a copper wire strung between strain insulators *I'*, *I'*. The feeder *F*, carried on top of the pole *p*, taps into this wire by means of tap *f* inside of the strain insulator. By means of pigtails *t*, *t'* the wire connects to the trolley hangers *e*, *e'*.

18. Underground Distribution.—In large cities where overhead wires are not allowed, the feeders from the station to the different parts of the system have to be run underground, even though the authorities may allow the trolley wire to be strung overhead. Under such circumstances the feeders are in the form of lead-covered cables and are run in underground conduits. The construction is similar to that already described for light and power distribution. Manholes are provided at intersecting points, so that the cables may be reached at any time for repair or inspection. Taps to the trolley wire are run up the poles, and the current is thus conveyed from the station to the trolley wire without large and unsightly feeders being in evidence.

LINE AND TRACK CALCULATIONS.

FEEDERS AND RAIL RETURN.

19. Economical Use of Feeders.—The general methods of calculating the size of line wires to deliver a given amount of power over a given distance have already been taken up. These rules also apply in a general way to the calculation of feeders for electric railways, but there are a number of special points that must be considered.

There is no problem involving as little prospect of ever having general rules laid down to cover all cases and all conditions as the problem of calculating the most economical amount of copper to install and the best method of disposing that copper to meet the requirements of a given street-railway service. It is true that the present practice of dividing the line into insulated sections has, to a certain extent, simplified the work of calculation, because each section can be considered as an independent line governed by its own local conditions of load. If these conditions of load could in any case be laid down with certainty, the problem for any particular case would be solved; but once solved for that particular case, the solution would be of little use to the engineer for application to other cases, because it is almost impossible to find any two roads or even any two sections of the same road that call for the same conditions of load, and, therefore, for the same distribution of copper. The design of the copper circuit is to a great extent the discreet combination of approximation, experience, and calculation. The calculation is easy, but the guesswork or approximation is rendered difficult by the variation of the load both in magnitude and position. It very often varies from zero to a maximum in a few seconds. During one part of the day the heaviest load might be on one part of the line and later in the day it might be on a section several miles away. Again, there may take place gradually a general shifting of the load more serious than a daily or weekly shift, due, possibly, to changes of attractions from one end of the line to the other, by a shift in the field of suburban improvements. Though overhead work may be installed under a design that meets satisfactorily almost every requirement of the present service, subsequent changes, such as the development of suburban property, may throw the system completely out of balance. The only thing to do then is to go over the work again and put copper where it is needed. But it is now a well-known fact that in promiscuously putting up copper, although it may be placed with good judgment from an electrical point of view and successfully fulfil its mission of raising the voltage to its normal value at the desired point, yet it can be put up at a net loss to the company. Copper is expensive, and in the effort to lessen the loss in the line, it is an easy matter to get so much copper strung that a condition arises where the money invested in copper would, if put out at interest in some other channel of business, pay the investors better than it does in the shape of feeder wire.

20. The conditions that confront the engineer, then, when he proposes to improve the service by stringing more feeders are as follows : By putting up more feeders and raising the voltage, a certain amount of energy is saved by doing away with some of the line loss, and the amount of this saving in watts or horsepower can be approximately calculated. By knowing what it costs to produce a unit of energy at the power house, the direct saving effected by the increase of copper can be at once obtained, and by knowing the cost of the additional copper installed, including the cost of construction, the interest on the cost of the copper may be computed. If the interest on this cost for one year proves to be more than the money value of the energy saved by the addition of the copper, it is being installed at a loss to the company. If it proves to be less, the addition of the copper is an economy. The rule that it pays to install more copper to raise the voltage, if the cost of the watts saved in one year exceeds a year's interest on the cost of the additional copper put up, is one that should always be kept in mind. It must not be forgotten, however, that the above limiting condition expressed in the form of an equation (interest on the cost = value of energy saved) does not include all the elements that modify the equation. When the feeding system is improved, it brings about a saving in a direct way; it makes the loss in the line less, and it brings about a saving in an indirect way that is just as important; for, by keeping up the voltage and thereby increasing the efficiency and speed at which the cars run, it not only decreases the number of cars necessary to conform to the conditions of a certain time table, but by improving the service, it attracts travel, especially in cases where there is a competing road. Even in cases where there is no competing road, an improvement in the service draws travel. Calling Q the interest on the cost, W the value of the energy saved, and S the money returned per year as a result of the raising of the E. M. F. by the additional copper, the modified equation will read (the present one reads $Q = W$) $Q = S + W$. This equation is more in favor of the added copper and it conforms more to the true state of affairs.

There must be a distinction made between the two conditions where the feed copper is working at an actual loss to the company and where it is working at a less economy than some other means of raising the voltage. The modified equation does not involve the question as to whether the additional copper is working at a less economy than some other means of raising the voltage, but it merely involves the important question as to whether it is working at a loss or not. The general limiting condition as expressed in the original equation, $Q = W$, might be generally true, but in some cases, when it comes to installing the alternative methods of raising the E. M. F., it would be found that any of these methods, on account of the local conditions or on account of the condition of the company, would be practically impossible. From this general discussion it can be seen that, when laying out the overhead work for any electric-railway system, future extensions should always be kept in mind if there is any prospect at all of such extensions being put in.

21. Division of the Overhead Work.—The overhead construction on an electric road may be divided into three main parts: the **feeders,** the **trolley wire,** and the **ground return.** The feeders require the greatest outlay of copper. At present, the common practice is to divide the trolley wire into sections, each fed by its own feeder, and under these circumstances the trolley wire does not help very greatly towards the general conductivity of the system. With the sectional system of distribution, the drop in the trolley wire, under ordinary circumstances, is not very great. If a car, however heavily it may be loaded, is just under the point where the feed wire connects to the trolley wire, there will be no loss in the trolley wire due to that car, because, as far as that car is concerned, the trolley wire is not in use; but as the car moves away from the tap, the amount of the trolley wire in use increases in direct proportion to the distance of the car from the tap. If the trolley wire is of the liberal dimensions advocated at the present time for mechanical reasons, the drop in it, even when the car has reached a point near the end of a section, is not very large, because the sections are comparatively short. Assuming that there is a single feeder tap, which is not often the case, to each section of trolley wire, and further assuming that the load on the section is evenly distributed, the trolley wire will be called on to carry but one-half of the feeder current. If, for some reason or other, all the cars happen to be bunched on one side of the single tap, the trolley wire will have to carry all of the current that the feed wire does, and the drop will be excessive, because the trolley wire is not designed to meet such abnormal requirements of load; nor would it be economical to so design it, for the excessive load is only temporary.

The trolley wire now put up is very much heavier than that used on the older roads, and it will carry quite a large current for moderate distances without an excessive drop. When the early roads were installed, feeders had not come into extended use; consequently, the small wire had to carry the whole load wherever it happened to be concentrated, and the drop was therefore excessive. It must be remembered, however, that the loads carried then were not nearly as heavy as those carried now, because the cars and motors were much smaller.

22. The Ground Return.—The next element to be considered is the ground return. Some roads, principally conduit or slot roads, do not use the ground return. They are called **metallic-return** roads; i. e., they have copper wires to take the current out to the motors and wires to bring it back to the power station. Such roads have their advantages and their disadvantages. The principal advantage lies in the fact that with a metallic return, it takes two grounds to tie up the road, and these grounds must be on opposite sides of the system. As there are means of detecting a ground as soon as it occurs, it can be removed before the next one takes place. This system is well adapted to slot roads, where the source of trouble is not so easy to get at as it is on open work.

On overhead work, it is almost the invariable rule to use the rails to bring the current back to the power house. The rail itself, on account of its large cross-section, has large current-carrying capacity, but at the joints where the rails come together, the conductivity is in time greatly impaired by rust, so that extra means must be provided for carrying the current around the joint. The means provided are pieces of copper connecting the rails together and called **bonds.** At one time the earth was for the most part relied on to conduct the current back to the power house. On account of its great size and cross-section, it was assumed that its resistance was zero and that, therefore, no drop in voltage would take place through it. Under this assumption the conductivity of the rails was neglected; in some cases they were bonded with a small iron wire and in many more cases they were not bonded at all. In course of time the idea that the earth offered a return circuit of zero resistance was abandoned, and it was further found that most of the losses in transmission were due to a poor return circuit. As a matter of fact, the earth as a conductor cannot be relied on in railway work at all. Even admitting that it were a good conductor, standard track construction in cities is such that it would be almost impossible for the current to get from the rail to the earth through the many poor conducting mediums, such as ties, concrete, etc., interposed directly in its path. As an example, to show how little the earth can be relied on as a conductor and how erratic any calculations in regard to it might be, take the case shown in Fig. 29, where *A*, *B*, and *C* are three points in a straight line. It has been experimentally proved that the resistance of the earth between points *A* and *C* is just as liable to be less as it is to be more than that between *A* and *B*. The

Fig. 29.

resistance between any two earth points is found to be greatly influenced by any gas or water pipes that may be near them; it is also influenced by the way in which the earth's strata may lie. The fact has also been proved that the resistance between any two points depends more on the area of contact between the earth plates and the earth than it does on the distance between the earth plates. As a result of the information gained from such experiments and as a result of the practical good secured in many cases by not only properly bonding the rails together, but also by connecting the bonds together by means of a bare copper wire zigzagging down the center of the track throughout its whole length, it has come to be the rule to ignore the carrying capacity of the earth altogether and to rely on that of the rails, the copper bonds, and return copper conductors. In fact, everything possible is done to keep the current out of the earth; if, after leaving the rail, it would confine itself to the earth, no harm would be done; but in its efforts to get a low-resistance path, it goes into any pipes or cable sheaths that may be in its way, and where it leaves them to go back to the rail or station, it eats the metal away. Under the proper conditions, this process, known as **electrolysis,** will eat a hole in an iron pipe in a year. Very naturally, the gas and water companies object to having their property ruined in this way, and in some countries have brought about legislation requiring that at no place on the system shall there be over a certain drop between the rail and neighboring pipes. There have been several means devised for combating the electrolytic effect of the leakage current in an electric railway with a rail return.

23. On an electric road it is not as essential that the E. M. F. should be kept constant at all times as it is that it should be kept up to or above its normal value at all points on the road. To keep the E. M. F. constant at all points is impossible; to keep it near the normal value is possible, if the return circuit is good and the trolley wire is fed as it should be.

CALCULATION OF TRACK RESISTANCE.

24. Resistance of Mild Steel.—The resistance of mild steel, such as rails are made of, varies considerably with the composition of the metal. For purposes of calculation, we will take the specific resistance of mild steel as 7 times that of copper. This is a fair average value, but some of the harder varieties of steel would run considerably above this. If we take the resistance as 7 times that of copper and the resistance of 1 mil-foot of copper as 10.8 ohms, then the resistance of 1 foot of mild-steel wire 1 mil in diameter would be 10.8 × 7 = 75.6 ohms.

25. Relation Between Weight of Rail and Cross-Sectional Area.—Rails are always designated by the number of pounds that they weigh per yard. Thus, a rail weighing 60 pounds per yard is known as a 60-pound rail; one weighing 80 pounds per yard as an 80-pound rail, and so on. The resistance of a rail, of course, depends on its sectional area, so that it is convenient to bear in mind the relation between the weight in pounds per yard and the cross-sectional area in square inches. Fortunately, this relation is a very simple one, because it so happens that the weight in pounds per yard divided by 10 gives the cross-sectional area quite exactly. For example, an 80-pound rail would have a cross-section of $\frac{80}{10} = 8$ square inches. We may write

$$A = \frac{W}{10}, \qquad \textbf{(1.)}$$

where A = area of rail section in square inches;

W = weight of rail in pounds per yard.

Rule.—*To find the area of cross-section of a rail, divide the weight in pounds per yard by 10.*

Rails now in use run from 35 pounds (too light for a car having motors on it) to 100 pounds per yard (an extra heavy steam rail). The rails most commonly employed run from 60 to 80 pounds per yard, and the general tendency is to increase the weight of rails.

26. Relation Between Weight of Rail and Resistance.—A copper bar having 1 square inch cross-section would have an area of 1,273,236 circular mils. The resistance of 1 mil-foot of copper is 10.8 ohms; hence the resistance of a bar of copper 1 square inch in cross-section and 1 foot long would be $\frac{10.8}{1,273,236}$ and a bar 1 yard long would have a resistance of $\frac{10.8 \times 3}{1,273,236}$ ohms. If we take the resistance of mild steel as 7 times that of copper, the resistance of a bar of mild steel of 1 square inch in cross-section and 1 yard long would be $\frac{10.8 \times 3 \times 7}{1,273,236}$ ohms. A bar having an area of 2 square inches would have $\frac{1}{2}$ this resistance, and the resistance of 1 yard of a rail having a cross-sectional area of A square inches would be

$$R_y = \frac{10.8 \times 3 \times 7}{1,273,236 \times A} = \frac{.000178}{A}, \qquad (2.)$$

where R_y = resistance per yard of rail;
A = area of cross-section of rail in square inches.

Rule.—*The resistance in ohms of 1 yard of mild-steel rail is equal to .000178 divided by the area of cross-section of the rail in square inches.*

27. We can also express the resistance in terms of the weight per yard.

$$A = \frac{W}{10};$$

hence,

$$R_y = \frac{.000178}{\frac{W}{10}} = \frac{.00178}{W}, \qquad (3.)$$

where R_y = resistance per yard;
W = weight per yard.

Rule.—*The resistance in ohms of 1 yard of mild-steel rail is equal to .00178 divided by the weight in pounds per yard.*

Sometimes it is more convenient to have the resistance expressed in terms of 1,000 feet of rail. 1,000 feet $= \frac{1000}{3}$ yards; hence,

$$R_m = \frac{.00178 \times \frac{1,000}{3}}{W} = \frac{.6}{W}, \text{ approximately,} \qquad (4.)$$

where R_m = resistance per 1,000 feet of rail;
W = weight per yard.

Rule.—*The resistance in ohms of 1,000 feet of single rail, not including joints, is equal to .6 divided by the weight in pounds per yard.*

Formula **4** therefore gives the resistance of 1,000 feet of single rail, not including joints. For two rails in parallel, as on a single track, the resistance per 1,000 feet would be $\frac{.3}{W}$, approximately, and for a double track it would be $\frac{1}{4}$ that given by formula **4**, or $\frac{.15}{W}$.

Example.—What is the resistance, not including joints, of 2 miles of single track laid with 60-pound rails?

Solution.—Since there are two rails in parallel, the resistance per 1,000 feet will be $R_m = \frac{.3}{W}$ and the resistance of two miles will be

$$R = \frac{.3}{60} \times \frac{5,280 \times 2}{1,000} = .0528 \text{ ohm. Ans.}$$

28. In the case of an electrically welded rail, there is really no joint, electrically speaking, as the rail becomes continuous. Owing to the fact that, as a rule, extra pieces of metal are used in making the weld, the welded part may actually have a greater cross-section than the rail itself. In such a case, the above formulas include the joints; but for ordinary fish-plate joints they do not include the joint resistance.

RAIL JOINTS AND BONDS.

29. General Remarks on Rail Joints.—There is no feature about electric-railway construction that calls for more care and attention than the rail joints. It is not such a hard matter to get a joint that is mechanically good, but it seems to be a very difficult matter to get one that is electrically so, and even if it is good to begin with, it is a still harder matter to keep it in that condition. After a joint is once made electrically good, the only thing to be done is to watch it and test it at frequent intervals, to see that it is mechanically firm and that its resistance is as low as it should be, for the permanency of a joint as a conductor depends as much on its mechanical condition as it does on anything else. When a track is first laid and the rails and fish-plates are new, the joints carry a current satisfactorily, but in course of time the parts become rusty, and rust will scarcely conduct the current at all. The result is that a single joint may at length have more resistance than several hundred feet of the rail itself; there are even cases on record where a joint, on account of looseness and rust, refused to pass the current at all. To do away with all chances of such a condition arising, it is the practice to use bond wires to electrically connect the ends of abutting rails together. *Bond wires*, or *bonds*, are simply copper wires or bars provided with terminals to be driven into holes drilled near the ends of abutting rails. There are various ideas in use for improving the amount and quality of the surface contact between the bond and the rail. If, however, the joint is allowed to run down mechanically and become loose, it will be a matter of only a short while until its electrical conductivity will be greatly impaired or even altogether destroyed, for the continual vibration is almost sure to work the bond loose in time. It is a source of wonder how in the earliest days of electric railroading some of the roads could operate their cars under the conditions that were later found to exist in the rail return. The rail return is just as important a part of the circuit and can cause just as much loss of energy as the overhead wires.

In most cases, as soon as the voltage on the line begins to fall below normal, the first thing thought of is to put up more overhead feeders. Sometimes such feeders will do a great deal of good, but very often they do not help matters much. If the rail return is in good condition, the chances are that the addition of line feeders will help the situation; but if the rail return is in very bad shape—the joints loose and the bond wires loose or broken—overhead feeders will be a waste of money that should be spent in perfecting the bonds and joints. Increasing the copper in the line work when the track return is the place that should be fixed, amounts to about the same thing as trying to make water run more freely through a series of pipes by carefully cleaning the inside of some of the pipes when perhaps the others are choked with rubbish. Before putting up any more line feeders to raise the voltage at any given point on the line, the resistance of the feeders already feeding that point and the resistance of the rail return from that point to the power house should be carefully measured and the two compared. If they prove to be about the same, an improvement in either place will do the work. If the rail return proves to be in comparatively good shape, any further improvement in that place will not effect the desired change, because the loss is in the feeder, and it is therefore the feeder part of the circuit that needs attention. On the other hand, if the resistance of the rail return proves to be much higher than that of the feed circuit, the rail return is the place to be improved, and money put in feed wires is thrown away.

30. Distribution of Resistance in the Rail Return. Let us now take 1,000 feet of single-rail return and see how the resistance is divided between the rails, the bond wires, and the bond-wire contacts. Before this can be done, some weight in pounds per yard must be assumed for the rail and some definite size of bond wire must be selected. As the practice at present seems to be towards the use of a heavy rail, 80 pounds per yard might be taken as a fair average. As a rail bond should never be any smaller than a No. 0000 wire, whatever may be the weight of the rails employed, a No. 0000 bond wire will be taken in the following calculations. Rails in ordinary use are about 30 feet long; hence there will be ($\frac{1000}{30} = 33$) 33 rails in 1,000 feet of single rail. From the formula for single rail, we have $R_m = \frac{.6}{80} = .0075$ ohm per 1,000 feet. The resistance of 1,000 feet of 80-pound rail, neglecting the joints, is .0075 ohm. There is a bond wire to every rail, and every bond wire has two contact places. The bond wires need not average more than 1 foot in length, and there will be 33 bond wires in 1,000 feet of single rail. 1,000 feet of No. 0000 copper wire measures roughly .05 ohm; the resistance of one bond wire (1 foot) is $\frac{.05}{1000} = .00005$ ohm, and the resistance of 33 bond wires is $33 \times .00005 = .0016$ ohm, approximately. The resistance of the contact between the bond and the rail varies a great deal, depending on the area and quality of the surfaces exposed to each other; these in turn depend on the kind of bond-wire contact used and on the skill and care with which it is installed. Bond-wire contact resistances, under fair conditions even, vary from .000005 to .0008 ohm, so that it is safe to assume for purposes of calculation a value of .0002 ohm, as proposed by Dr. Louis Bell.* On a well-bonded road, the resistance per bond would not run as high as this, but on some roads it would run a great deal higher. As there are 33 bond wires per 1,000 feet and as each bond has two contacts, there will be 66 bond-wire contacts per 1,000 feet. With a resistance of .0002 ohm per contact, this brings the total bond-contact resistances per 1,000 feet up to $66 \times .0002 = .0132$ ohm.

Collecting the three values determined above, we have 80 pound rail resistance for 1,000 feet = .0075 ohm; resistance for 33 bond wires in the 1,000 feet of rail = .0016 ohm; resistance of the 66 bond-wire contacts = .0132 ohm. This makes the total resistance of the 1,000 feet of single rail amount to $.0075 + .0016 + .0132 = .0223$ ohm. This comparison shows that the bond wires and the contacts are

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* Power Distribution for Electric Railroads by Dr. Louis Bell.

responsible for two-thirds of the entire resistance of the 1,000 feet of single rail; so the fact that the rail has a bonded joint every 30 feet multiplies the resistance of the rail return by 3. By installing two bond wires instead of one, the resistance due to joints would be halved, making the total resistance of the 1,000 feet of single-rail return $.0075 + \frac{.0016 + .0132}{2} = .0149$ ohm. This reduces the total single-rail resistance per 1,000 feet to a value only twice what it would be if there were no joints or reduces it $33\frac{1}{3}$ per cent. The best method of reducing the resistance due to joints is to use a 60-foot rail instead of the standard 30-foot rail. This construction has the advantage of not only halving the number of electrical joints, and thereby halving the drop loss due to joints, but by halving the mechanical joints, it halves the pounding that the car has to go through, and in this way saves both the track and the rolling stock. Of course, a 120-foot rail would be much better still, but there is a limit to the length of rail that can be shipped and handled economically. The desirable feature of length pushed to its limit would call for one continuous rail for the whole road. Such a rail could not be rolled or shipped, but perfect continuity of the rail can be obtained by the electrical welding process. Experience has shown that where the rail is embedded in paving, the trouble due to expansion and contraction cannot exert itself. The paving prevents sudden changes in the temperature of the rails and also holds them so that they cannot move laterally.

The value .0223 ohm, it must be remembered, is the resistance of 1,000 feet of single rail including the joints. The resistance per 1,000 feet of single track, or two rails, would be one-half of this, .0111 ohm. The resistance per 1,000 feet of double track would be about .0056 ohm. It is easily seen that on a double-track road, with heavy rails and with the joints all welded, the resistance of the rail return might be brought very nearly down to a value where it could be ignored altogether in comparison with that of the overhead work; but as such an ideal condition of things would be very unusual, we will, for purposes of calculation, assume that the track is well bonded and that the resistance per 1,000 feet of single track is approximately .0111 ohm.

31. Bonds.—Rail bonds are made in a great many different styles, the differences between some of them being very slight. They are all designed, however, to get the best possible contact between the rail and the bond, also to withstand the tendency to break off under the action of the continuous vibration and pounding to which the joints are subjected when the cars pass over them. There are so many different kinds of rail bonds on the market that to describe them all would be out of the question, but it might be well to describe briefly several types, the construction of which brings them on the safe side of the 1 foot of No. 0000 wire assumed in the calculations.

32. Fig. 30 shows one form of bond; the conducting part *a* of this bond is flexible, being made up of a number of small flattened wires cast-welded into the terminals that attach to the rail. To install the bond, the fish-plate must be removed and two holes drilled in the rail to fit the plug portion of the terminal. The plugs are then pressed into the holes in the rails by means of a special press that forces them home until they not only fill the holes snug, but their heads also flatten over on the opposite side of the rail, thereby giving greater area of contact between the bond and the rail. The fish-plate is then screwed back into place. This bond belongs to what is known as the **protected** class, as the fish-plate not only protects it from mechanical injury

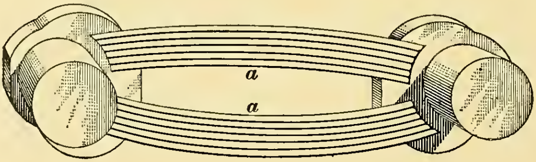


Fig. 30.

and the action of the weather, but also from the attacks of copper thieves.

Fig. 31 shows another type of protected bond, known as the *ball bond*, because a small steel ball is used to expand the contact between this bond terminal and the rail. As shown in the figure, the plug part of the terminal that goes into the rail is hollow. To fix the bond to the rail, the plug is slipped into the hole and a small steel ball is then driven through the hole in the plug; this serves to expand the plug into the sides of the iron hole and thus secures a good contact. If the first ball forced in goes through too freely, a little larger one is used. Fig. 32 shows another form of protected bond. This bond has a stranded conductor, but solid terminals, and the bond itself is quite short.

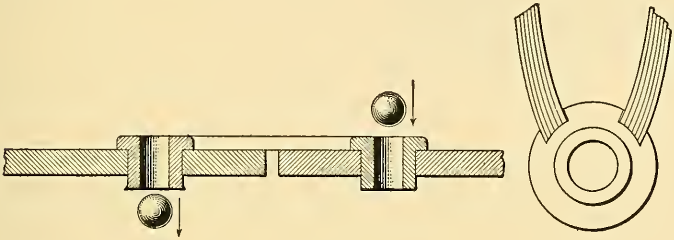


FIG. 31.

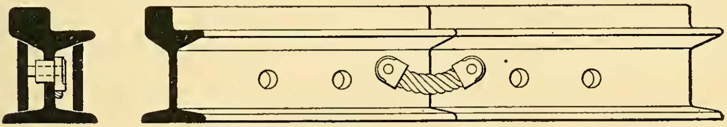


FIG. 32.

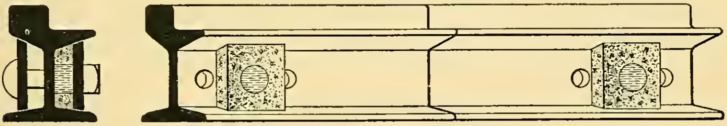


FIG. 33.

33. Fig. 33 shows a style of bond known as the **plastic** bond from the fact that the medium of contact is a paste or amalgam and is therefore plastic. This bond has the unique feature that the fish-plate itself is used as the bond proper, the plastic part merely insuring that there shall be a good contact between the fish-plate and the rails. A piece of cork holds the plastic compound in position near the side of the rails. The surface of the plate and rail is brightened before the plastic device is put in place, and as the contact surfaces are thereafter protected by the plastic compound, which remains soft, air and water are kept from the joints and rusting cannot take place. The idea involved in applying the plastic device can be more clearly seen in Fig. 34, which shows the method of its application to the bonding of old rails. In this case, a hole must be bored through the fish-plate and into the rail. The amalgam is shown at *b*. The above bonds have not been selected with the idea of putting forth the merits of the best ones to use, for there are many others that, with one or two exceptions, are perhaps just as good as the ones given, but they are given to show some of the many ways used to attach the bonds to the rails. There are bonds with threaded shanks, held in place by nuts and jamb nuts; others depend on pins; and others, again, have their ends welded or brazed to the rail.

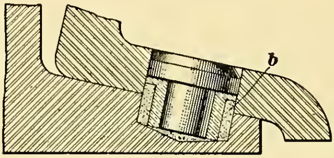


FIG. 34.

34. Disposal of the Bonds.—Having selected the kind of bond to be used in any case, the next question is, how shall they be disposed, and is it necessary to help them in any way by supplementary wires? Fig. 35 shows the style of bonding used in the early days of electric railways. In

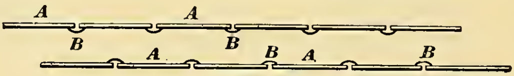


FIG. 35.

this figure, *A*, *A*, *A*, *A* are the rails and *B*, *B*, *B*, *B* the bond wires. Each rail is connected to the one abutting it. With the exception, perhaps, of the ends, the two lines of rail are not connected together; so that if a bond wire breaks and at the same time the iron joint happens to be very bad, the rail return becomes almost useless beyond the break as far as that line of rail is concerned.

FIG. 36.

If the bond wires are of ample size and are so installed that they can be relied on not to break, the style of bonding shown in Fig. 35 is good enough for all practical purposes; but, unfortunately, there can be no certainty that the bond wires will remain in as good a state as they are when they are put in. In spite of all precautions, they will break or become loose, and some steps must be taken to lessen the bad effects of such a mishap. Fig. 36 shows the first step taken in this direction. In this case, the nearest opposite bond wires are tied together with a cross wire, so that the rail return cannot be entirely ruptured unless both of the bond wires tied together give way. The chances of a complete break in the return circuit of either rail are lessened by the fact that the rails are thus tied together at frequent intervals. To still further insure the continuity of the rail return and to protect it against the evils of faulty bond wires, the scheme shown in Fig. 37 is sometimes adopted. In this case, not only are the rails bonded together as usual, but all the bond wires are connected together by means of a bare copper wire that zigzags down the track from one bond wire to the other. This auxiliary wire carries the current over any breaks that might occur and makes it almost impossible for such a thing as a dead rail to develop.

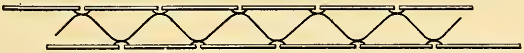


FIG. 37.

Besides this, it actually serves as an auxiliary wire in multiple with the rails. Of course, such a wire, since it is often no larger than a No. 6 B. & S., has a very small capacity compared with that of the rails themselves, as has been shown by the fact that in several instances the continuity of the rail return has become so bad that this zigzag wire has burned off on account of the large current that it had to carry. With such a construction, however, it is almost impossible for the breaking of several bond wires to seriously interfere with the running of the cars.

On some roads, the ground return is supplemented by an extra ground feeder running along the track, either supported on the poles or buried underground, as shown in Fig. 38. This auxiliary return is tapped to the rails at regular intervals. Such a feeder is especially effective where the road curves, so that the end of the line is much nearer to the power house than the intermediate portions of the line. In cases of this kind, it pays to string a ground feeder across lots to the power house to avoid having the current follow the roundabout path offered by the rails. Where there is a double track, it is customary to bond the two lines of rail together at intervals of 400 or 500 feet. Special care must be taken to do a good, safe job of bonding at all crossings and special work, for it is there that the cars do most of the pounding and the bond wires are most likely to be worked loose or broken. In fact, it is a good idea to duplicate the bonds at such points, for if one breaks, the other still preserves the continuity. All joints between a supplementary ground-return wire and the bond wires should be well soldered, and where the rail-return connection is made at the power house, it should be a metallic one between the rail and the negative bus-bar, and not through the agency of a ground plate alone.

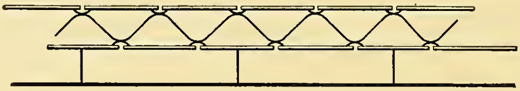


FIG. 38.

35. In perfecting the rail return, the best rule to keep in mind is to make it as good as it can be made, for even then the chances are that it will not be any too good. In perfecting or improving the rail part of the circuit, there is not the same chance of exceeding the economical limit of investment that there is in the overhead work, because the amount of copper involved is comparatively small. The rails are a necessary part of the equipment, anyway, and if full use can be made of them as conductors, so much the better. If the track is thus used to carry the current, it effects a saving by doing away with the necessity of a solid copper return. Again, where the conditions prescribe that the drop in voltage between the station and the cars be limited to a certain amount, this drop includes the loss in the track return as well as the overhead line, so that if the track resistance is low, the bulk of the drop may be made to take place in the overhead-line work, thus helping to keep down the size of the feeders. In the track circuit there are two or four lines of rails, as the case may be, and each line of rails has carrying capacity for a certain amount of current; none of this carrying capacity should be thrown away by reducing the conductivity of the rails with poor or insufficient bonding.

36. Cast-Welded Joint.—Cast-welding is now frequently resorted to for bonding the rails. It makes a strong joint mechanically, and if the work is properly done, the resistance of the joint may be as low, if not lower, than that of a corresponding length of rail. The ends of the rails are first carefully cleaned by means of a sand blast, and are then held in position by a special clamp that forms a mold around the joint. The cast iron *l*, Fig. 39, is then poured into the mold from a portable cupola. The joint so formed is very stiff

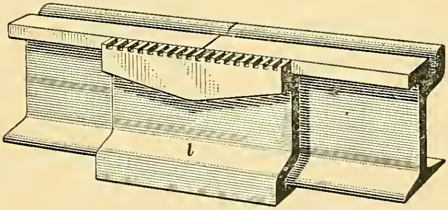


FIG. 39.

and is of high electrical conductivity. The cast iron *l* is approximately 100 pounds in weight and covers the rails for a length of 10 or 12 inches.

37. Electrically Welded Joints.—In this method of joining the rails, the abutting ends are first cleaned and then held by a special arrangement, by means of which they may be pressed together after they have been brought to a welding heat. A heavy current is then sent through the joint until it becomes heated. This current is usually furnished by a special welding transformer that is capable of delivering a very large current at low pressure. This transformer is usually supplied with alternating current that is obtained from a rotary transformer or motor generator, operated by the 500-volt trolley current. The electrically welded joint has a very low electrical resistance if the work is properly done. It is, however, hardly as strong mechanically as the cast-welded joint, unless it is reenforced by side pieces. The cast-welded joint is used more widely than the electrically welded joint, but the great majority of roads use the regular fish-plate joint.

THE TRACK.

38. General Remarks.—There is no class of track work that calls for more care and attention to details than that for a track on which cars equipped with heavy electric motors are to run. There are two general ways of propelling street cars over the road. One way is by means of a force outside of the car itself, as found in the cable road; and the other is by means of a force applied directly to the car axles, as on cars propelled by air, steam, and electric motors. The latter way has the advantage that each car is an independent unit, so that trouble on one does not necessarily interfere with the running of the rest. But, on the other hand, the wear and tear on the track on an axle-driven system is much greater than it is on a cable system. This is due not only to the increased weight of the independent unit incidental to its carrying all its own driving devices, but to the continual slippage of the wheels and hence grinding effect that takes place under certain conditions. This latter point is proved by the fact that on grades the up-going rail always wears out first, because this is the track on which the most spinning of the wheels takes place. This effect is often noticeable on the head of the rail, even on level track; the rail looks as if some one had gone along with a small emery wheel and ground the rail top into a series of arcs of circles—quite small, it is true, but plainly noticeable. Added to these two features is that of the much higher rate of speed at which self-contained cars run. As a result of all these influences, whenever a horse-car line is converted into an electric line, it is in most cases necessary to change not only the weight and style of the rail used, but the whole roadbed construction. Great care has to be taken to support the joints between the ends of the abutting rails in a thorough and substantial manner, because it is here that the pounding takes place and the greatest wear occurs. An electric road requires the exercise of even more care in the perfection of its track work than any other kind of road, because not only are the rails a part of the electrical circuit in most cases, thus making it necessary that they be electrically continuous from one end of the line to the other, but the life of the overhead work and the rolling stock is indirectly but very largely dependent on the quality of the track.

In order to get the best electrical results out of the rail as a return conductor, the joints should be able to carry a current with as little loss of energy as the same length of the rail itself. There are means provided for securing this condition when the track is new, but no means can be provided for preserving the electrical continuity if the joints are allowed to run down and become loose. If the joints are good and the rail is smooth, there will be no trouble in keeping the trolley pole on the wire, unless there is a defect in the pole or wire itself. Such a trouble would be local and easily remedied. But if the joints are bad, there will be no end of trouble, due to the pole jumping off the wire.

Nothing is harder on trucks and car bodies than a bad track; the pounding and jolting loosen the truck and motor bolts, wreck in course of time the suspension rigging and let the motor down on the pavement; it causes excessive teetering, setting of springs, and breaking of axles; it is hard on the bearings and just as hard on the brushes, with the result that the commutator soon gets in bad shape and troubles from flashing, grounds, and open circuits begin.

39. The kind of roadbed and rail to be used depends on where the road is located. If the soil has a very poor bottom, such as is the case in New Orleans, La., the subwork of the roadbed must be much more substantial than there is any need to be on soil that is firm and lays on a rock bottom, such as is found in New York. Where the proposed road runs through the country, it is the custom to use a **T** rail ; in cities, on paved streets, the girder rail is used ; but on account of its easy riding qualities and less cost, the trend is towards the use of the **T** rail wherever it is possible.

It is a well-known fact that in sections where the wagon traffic is heavy, the rail gets a great deal of its wear from this traffic. All light and medium vehicles are built to standard gauge to fit the track, and the heavier ones of wider gauge run with one wheel on the rail while the other one cuts a groove alongside of the other rail. To offset any inducement that the rail might naturally offer to wagon traffic, the plan was adopted of so shaping the rail and so bringing the paving up flush with its head, both inside and outside of the track, that there would be very little tendency for the wheels to follow the line of the rail. Wagon traffic takes the path of least resistance ; one way, therefore, to lessen the traffic on the rail is to make the paving on both sides of it good.

40. Staggered Joints.—In placing the rails, opinion is divided as to how the joints should be disposed ; some engineers are in favor of staggering the joints, while others prefer to put the joints opposite each other. The natural advantage of the broken or staggered plan is that if the joints are in poor condition, the jolting of the car is not as severe passing over them one side at a time as it is passing over both sides at the same time, as is the case with the joints opposite; on the other hand, when the joints are staggered and are in bad condition, the car, especially if it is a long body on a single truck, acquires a disagreeable side rolling motion, very much like the motion due to a sprung axle. On double-truck cars the effect is not so marked. The general practice is, however, to use staggered joints.

While the importance of making the track as good as possible has been realized for many years, it is only within the last few years that tracks have been constructed to withstand the hard usage to which motor cars subject them. Even high-grade concrete meets with liberal use in the subwork of such roads. The steel cross-tie threatens to take the place of the wooden one, and the old-style tie-rod is giving way to a tie-beam as large as the rail itself.

THE ROADBED.

41. The permanent character of the track as a whole depends greatly on the character of the roadbed; if after the substructure is laid, it gives or swerves in places, everything that rests on it gives and swerves also, so that in course of time the surface of the track becomes undulating and serpentine in outline. Electric roads as far as possible now follow steam-road practice in their roadbed and track work, and for out-of-town work they could not do better. Fig. 40 shows a standard steam-road construction. The same care and exactness that are observed in steam-road construction should be observed in electric railroading, where the train speeds are often almost as high and other conditions just as severe.

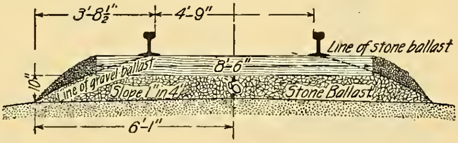


FIG. 40.

42. Methods of Installing Electric Roadbeds.—On suburban electric roads, the steam construction can be followed closely. It frequently happens, however, that electric roads are run in streets that if not already paved will be at some future time, and hence the conditions are somewhat changed. The methods of building electric roads differ so radically that it can be truly said that the only elements of construction in common to all electric roads are the earth and the rails. Some roads have wooden cross-ties, some metal, and others have no cross-ties at all. One road must build an expensive substructure for its roadbed and another, on account of natural conditions, may not have to lay scarcely any roadbed. There can be no better way of bringing out these several points in construction than to take examples of roads on which they occur; but before doing this, we will consider the most common forms of rail in use and the conditions to which they are best adapted.

RAILS.

43. T and Girder Rails.—There are two kinds of rail in common use, the **T** rail and the girder rail, both of which

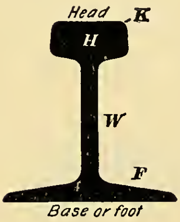
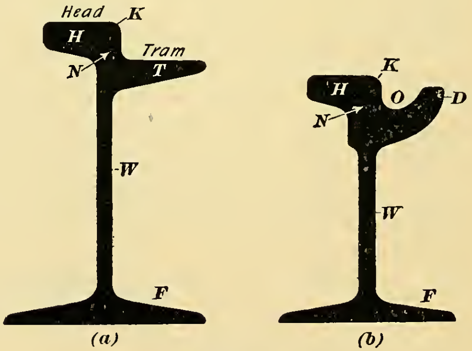


FIG. 41.



(a) (b)

FIG. 42.

get their names from their general shape. Fig. 41 shows a type of **T** rail used for cross-country, suburban, elevated, and underground roads, where the wagon traffic does not have to be considered. *H* is the head, or ball, of the rail, *W* is the web, and *F* is the flange, or foot. A **T** rail is called a center-bearing rail, because the center of the head is directly over the center of the web. Fig. 42 (*a*) and (*b*) shows two types of girder rail ; (*a*) is known as a **tram rail** on account of the tram *T* and (*b*) is known as a **grooved rail,** because it has the groove *O*. In Fig. 42 (*a*) and (*b*), *H* is the head ; *W*, the web ; *F*, the flange, or foot; *N*, the neck; *D*, the lip; and *K*, the gauge line or line that the heel of the gauge touches when gauging the distance apart of the rails. The tram rail is the first in order of invention, and it is still more used than any other type of girder rail.

44. Grooved Rail.—The grooved rail was introduced as a means of diverting wagon traffic from the rail, and in this it has succeeded quite well ; but in the earlier forms of grooved rail, it was found to be a source of constant trouble to keep the ice, dirt, and stones out of the groove. The presence of this foreign matter not only increased the power required to run the car, but it also introduced an element of danger, as a small stone could throw the car off the track. In modern grooved rails, however, such as that shown in Fig. 43, this bad feature is very much mitigated by the shape given to the groove. For a given groove, there is always a given shape of car-wheel flange that is best suited to that groove ; so that in buying car wheels, due regard must be had for the shape and size of the groove that they are to run in, otherwise there will be excessive wear in the groove and on the wheel flange. A wheel flange must be of a certain depth in order to be safe ; if the depth of the groove and the depth of the flange of the wheel are about the same, the least bit of wear in the tread of the wheel will let the weight of the car down on the flange, where it is not intended to be and which will not

Fig. 43.

stand it; if the wheel flanges are deeper than the groove, the wheels cannot be used at all. A track of grooved rail must be gauged to exactness, because it offers two chances for the wheels to bind. If the gauge is too narrow, the outsides of the wheel flanges bind against the heads of the rails; if the rails are too far apart, the insides of the wheel flanges bind against the side of the groove.

45. Standard Track Gauge. — The standard track gauge is 4 feet $8\frac{1}{2}$ inches, as measured by means of a gauge such as that shown in Fig. 44 (*a*). The car wheels are pressed on the axle to 4 feet $8\frac{1}{4}$ inches by means of a gauge similar to that shown in Fig. 44 (*b*). To apply such a gauge correctly, one end of the gauge should be free to move laterally about $2\frac{1}{2}$ inches, when both of the notches engage the flanges of the two wheels. **T** rails are much more economical from the operating point of view than girder rails, because however much the tread of the wheel may wear down or be ground down, there is nothing for the flange of the wheel to ride on.

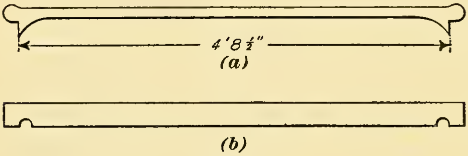


FIG. 44.

46. Rails With Conical Tread.—The treads of wheels are conical; that is, the diameter of tread next to the flange is larger than its diameter at the outside edge. This is done to allow the car to center itself on the track when the two wheels on the same axle are of different sizes. The device probably performs its function when there is no greater difference in the wheels than is found on two wheels of the same make just as they come from the foundry; this difference is, as a rule, not more than $\frac{3}{8}$ inch in the circumference. But the beveled tread cannot be expected to amount to very much as an equalizer where the difference in diameter of the two wheels is $\frac{3}{8}$ or $\frac{1}{2}$ inch. Such a state of affairs should not be allowed to exist, on account of the slippage it causes and for other reasons; but, unfortunately, in some cases it does exist. The general rule has been to make the top of the rail level, with the result that until there is a certain amount of wear in either the rail head or the wheel tread, the traction surface between the two is a straight line. In conformity with the observed fact that the side of the rail head next to the gauge line always wears down first, to meet the bevel of the wheel, the very sensible idea is now being practiced of making the top of the rail head also beveled to conform to the bevel on the wheel tread; the result is that the rail and wheel are a fit to begin with and do not have to wear down to that condition. This construction is said to effect a saving of about 33⅓ per cent. in the life of the wheel and rail. Fig. 45 shows a girder rail


FIG. 45.


FIG. 46.

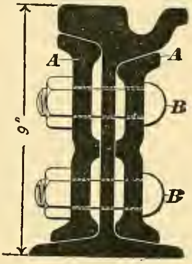


FIG. 47.

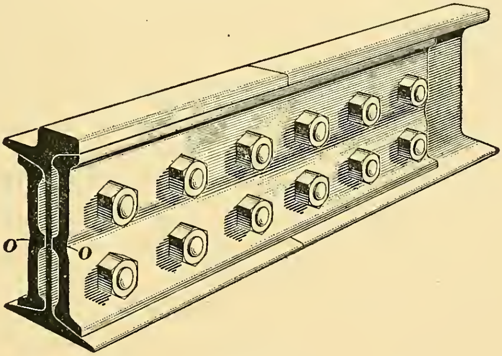


FIG. 48.

with a straight top; Fig. 46 shows one with a bevel top. Fig. 47 shows a section through a complete girder-rail joint. *A*, *A* are the **splice bars,** or **fish-plates,** so designed that they stiffen the joint. They are held up to the rail by **track bolts** *B*, *B*, which pass through the web of the rail. Fig. 48 shows a completed joint. Note the cross-section of the fish-plate; the rib at *O*, *O*, when the track bolts are screwed home, gives somewhat the effect of a lock washer and at the same time insures a definite contact surface between the plate and the rail. There are a great many patented devices in use for stiffening the joint and giving it solidity, and all of them have some merit; but the device that seems to be gaining the most favor with railway men is the cast-welded joint, which has already been described.

47. Guard Rails, Curves, and Special Work.—All roads have a greater or less number of crossings, curves, branch-offs, cross-overs, etc., and since these are different from straight track, in that they involve special care and precautions in their installation, they are all included under the general name of **special work.** Important special work is made up complete at the steel works and is shipped ready to install. When the work is in several pieces, ends that go together have the same mark, so that the trackman can make no mistake in his hurried efforts to complete the job without interfering with regular traffic. As the work of making up special work must be carried out with great precision (a difference of $\frac{1}{4}$ inch in the angle at which one arm of a frog or crossing sticks out may cause no end of trouble), it is carried out step by step, as follows: The site of the proposed work is first measured up carefully and a drawing of the survey made. This drawing is then carefully checked up and is used as a means to lay the work out in actual size with chalk on a hard, smooth, maple floor, known as the laying-out floor; if the job checks up all right, the floor lines and angles are used as a guide for making wooden templets to be used by the patternmaker and the rail bender. When the separate parts of the job are complete, it is set up in the laying-out yard, where any slight errors or inaccuracies due to uneven shrinkage in the cast parts of the job or to want of care in the bending are detected.

In the switch, frog, and crossing part of special work, the greatest wear takes place at the points and breaks. On this account, several schemes have been adopted for not only increasing the hardness of the metal at these places, but for making the support stronger, so that the effect of the pounding will be less. There are many different styles of this intersection work. Fig. 49 shows one make of crossing, and the other makes are much the same in general appearance. Hardened centers *a* of manganese steel or other hard kind of steel are used at the points to prevent wear and hammering-out.

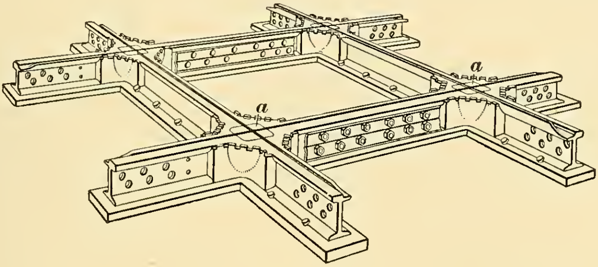


FIG. 49.

48. Curves. — Curves are of two kinds, **simple** and **compound,** or **transition,** curves. A simple curve is one that is described with but one radius throughout its length. A compound curve is one so constructed that the radii becomes shorter as the middle point of the curve is approached from either end. A compound curve is easier riding than a simple curve. Street-railway curves are always designated by the radius at the center. Long curves of light rail are sprung in, as a rule, that is, the rail is pried over with a bar and spiked into position, the paving being relied on to keep the track in place. The main objection to "springing in" a curve is, that if done on a curve of too short a radius or with heavy rail, the job in course of time will give trouble at the joints; the ends of the rails straighten out and make an angle at the joint. This means that the car trucks in rounding such a curve will change direction in jumps, instead of gradually, and impart to the car a disagreeable, jerky motion not to be found on a curve that is smooth and regular. On curves of heavy rail and moderate radius, a portable rail bender should be used, while shorter curves should be bent to a templet with a power bender.

49. A very important point about laying out a single-track curve is to be certain that a car will go around it freely without either end overhanging the corner of the sidewalk or striking any obstruction. On double-track curves is also introduced the feature of two cars being able to pass each other without danger. It is not absolutely essential that the curves be such that two cars can pass each other on them, and in many existing cases it cannot be done. Very often, however, it involves but a small additional cost to so construct the curves that the cars can pass, and it is in the long run the best thing to do. Whether or not a curve will allow cars to pass on it depends on the following: the length of the car; the width of the car; the amount that the ends overhang the wheel base; the distance between the track centers; the curvature; the elevation of the outside rail; the length of wheel base; and, on double-truck cars, the distance between trucks. Also, the matter of fenders should be taken into account, as a fender increases the effective length of the car. As the trucks on a double-truck car are relatively nearer the ends of the car, the overhang in the center must be considered. The best plan is to lay out on paper and to scale a plan of the proposed curve; then, by means of a pasteboard dummy that scales the dimensions of the outside lines of the car, the actual clearance at all points can be readily determined. The positions of the car wheels must be indicated by holes through which the track can be seen, or transparent paper must be used, so that the dummy can be made to take the right path around the curve. Another point to be looked after in cutting out a dummy to try on paper is to see that the widest part of the car is represented. To insure some degree of safety to the heads and arms of passengers, the clearance on both sides of the car should be at least 12 inches, if they are to pass each other on curves. Special attention must be paid to this feature where the center-pole method of line construction is used. There are many roads on which the curve clearance is not over 2 or 3 inches, but in most of such cases there is a rule against passing on curves.

50. Transition, or Compound, Curves.—These curves are formed by combining curves of different radii, so that the entrance of the car into the curve shall be gradual and a sudden shock avoided. The theoretically correct method of laying out a curve would be to make a true spiral connection between the end of the straight track (called the tangent) and the center of the curve, but this would be practically impossible. Some engineers advocate a near approach to such practice by starting with a radius of some 600 feet or more and changing the radius every 2 feet,

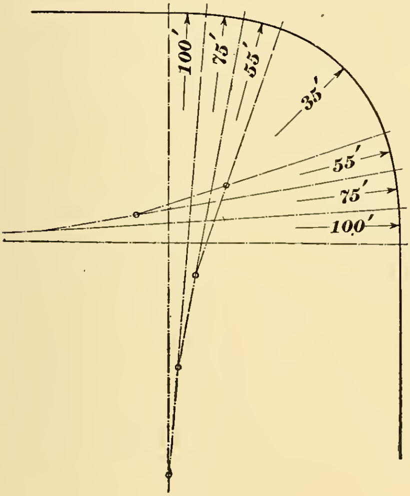


FIG. 50.

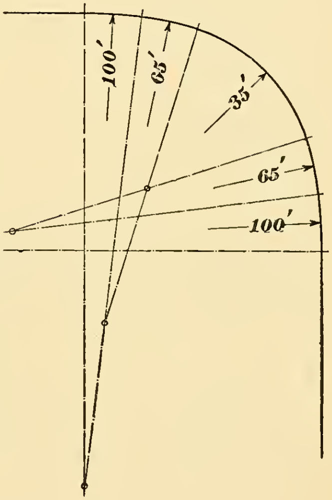


FIG. 51.

as measured along the track, when laying out the approach to a main curve of, perhaps, 35 feet radius. Such frequent change of radius would be very difficult for a trackman to accomplish, and would probably not be done; it is sufficient to change the radius at distances equal to the length of the wheel base, an initial radius of 100 feet being large enough for street-railway work. It is not easy to construct switches for a greater radius, and since they are used on probably 50 per cent. of the curves, this must be taken into consideration. In Fig. 50 the transition curves for a main radius of 35 feet are shown. Each chord, or length of curve having the same radius, is about equal to the wheel base of the cars, and there are three curves completing the transition, having radii, respectively, of 100, 75, and 55 feet. Fig. 51 shows a curve with only two transition curves. In both cases the initial curve has a radius of 100 feet, and the remaining curves should be divided equally between that radius and the radius of the main curve. Thus, for the curve forming the junction of the 100-foot and 35-foot curves, a radius of 65 feet, about midway between these numbers, is taken.

51. Designation of Special Work.—Fig. 52 (*a*) shows a *plain curve*, in the sense that it is not complicated by any branch-offs, turnouts, or other special features. Such a curve can be simple or compound, single or double, right-hand or left-hand. Fig. 52 (*b*) shows a *left-hand branch-off* and Fig. 52 (*c*) a *right-hand branch-off;* these are used where a branch road leaves the main line. Facing the point of departure of the branch from the main line, a right-hand branch-off turns to the right and a left-hand branch-off to the left. Fig. 52 (*d*) is known as a *connecting curve and crossing*. In the figure, the curve is a right-hand branch-off to the horizontal straight track and a left-hand branch-off to the vertical one. Fig. 52 (*e*) is what is known as a *plain* Y. Fig. 52 (*f*) is a *three-part* Y and Fig. 52 (*g*) a *through* Y. The three-part Y can be used instead of a loop to turn single-end cars at the end of the line. Fig. 52 (*h*) is known as a *reverse curve*, and must often be used where a cross street is broken at the main street. Fig. 52 (*k*) is a *right-hand* and Fig. 52 (*l*) a *left-hand cross-over*, used to cross over from one track to the other. These are very convenient devices to place here and there in a main line to turn cars back, either when they are crippled or to get them

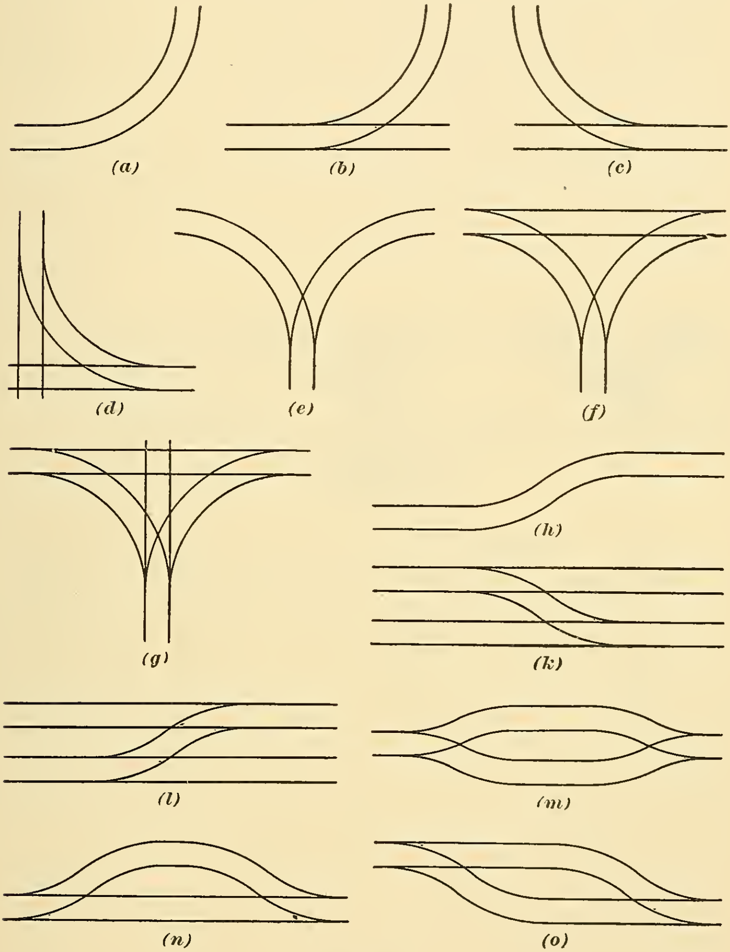


Fig. 52.

on their time after a long delay. When it is practicable, a cross-over should be put in so that its switch points will lay in the direction of travel on the two tracks. Fig. 52 (*m*) shows a *diamond turnout;* Fig. 52 (*n*), an ordinary *siding*, and Fig. 52 (*o*) what is called a *thrown-over turnout*, seen very often in temporary work, where it is of the nature of a temporary cross-over to avoid a gang of workmen.

52. Guard Rails.—Guard rails are rails provided with a protecting flange to prevent a car from climbing the rail on a curve. Guard rails can be solid or made up. Girder guard rails are, as a rule, solid; **T** rails are made up. Fig. 53 shows a section of a girder guard rail and Fig. 54 shows a section of **T** rail provided with a guard. The **T** rail need only be provided with a regular guard where it is used in a paved street. In country work, the steam-road practice of laying a second line of **T** rail next to the inside-track rail is adopted. This practice is also adopted, as a rule, on bridges, where the guard rail is, however, laid beside both track rails. The best authorities are inclined to the belief that a guard rail on the inside, or short rail, of a curve affords ample protection, but it is common to see a guard on both the inside and outside rails of short curves. At any rate, it is not safe to rely on the flange of the outer wheel alone to keep the car on the track, for car wheels in street-railway service, on account of the heavy weight attached to the axle and also on account of the nature of the special work that they have to jolt over at times, are addicted to the trouble of broken or chipped flanges. A wheel with such a defect in the flange is almost certain to climb the rail if that wheel is on the front end of the car as a leader. As in the case of ordinary grooved rail, a great deal of judgment must be used to select a groove that is adapted to the flanges of the wheels used.


FIG. 53.

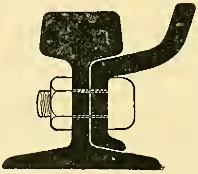


FIG. 54.

EXAMPLES OF STREET-RAILWAY TRACK CONSTRUCTION.

53. Fig. 55 shows a cross-section of a very substantial roadbed used in the State of New York. The figure shows a single track only, although the road is double track. A trench 23 inches deep is opened up 18 feet wide. This is well rolled and filled to a depth of 8 inches with 2-inch broken stone, soft spots in the rolled surface being dug out and also filled with the stone or other solid material. The stone is rolled until it is firm at a depth of 8 inches. On this ballast are laid the ties, 6 in. × 7 in. × 7 ft. 6 in., a little less than 2 feet between centers, except at the joints, which are supported by three ties about 15 inches between centers; 60-foot rails are then laid on the ties, ends butted and joints staggered. Before jointing, the ends of the rails and the joint plates are well cleaned to take the bonds. The rails are then coupled, the plates bolted tight, brace plates installed every 3 or 4 feet, ties lined up and spiked to the rail. The track is then lined and surfaced and the space between the ties filled with broken stone, well tamped to the top of the tie. The rail is then finally lined, the joints secured, and the broken stone or concrete brought up to the paving.

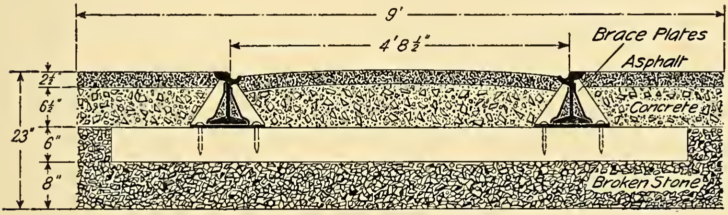


FIG. 55.

54. Fig. 56 is an example of roadbed construction on a weak subsoil, and Fig. 57 shows a very novel method of paving to a **T** rail. In the roadbed construction in Fig. 56, a trench 36 inches deep and the width of the tracks is dug; the trench, as shown by the figure, is filled to a depth of 29 inches with successive layers of 12-inch hard earth and rock well beaten down; 10-inch earth, pebbles, clay, sand, and rocks, well tamped; 7-inch new concrete; and 6 in. × 8 in. × 8 ft. hard pine ties, previously boiled in asphalt, are laid on the concrete to take 80-pound **T** rails. At joints the ties are supported on steel plates bolted to the concrete. The track is 3 feet 6 inches gauge and 12 feet between the centers. The paving is flush with the head of the rail on the outside. On the inside of the rail it is brought up, except at joints, to the lip of an **L** plate supported, as shown in Fig. 57, by the foot of the track rail and tied by a bolt that passes through it, the web of the rail, and the body of a **Y** filler, which acts as a groove for carriage wheels. At the joints where the **L** rail is discontinued, the groove is formed by stone blocks set in a steel frame. This method of construction, while somewhat bold, has given great satisfaction.

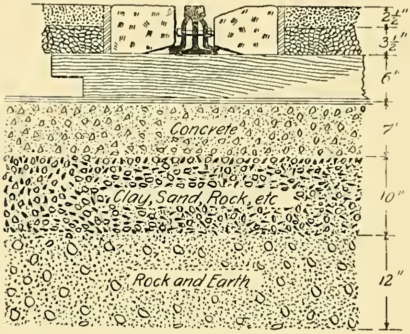


FIG. 56.

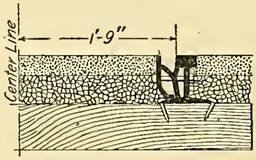


FIG. 57.

55. Fig. 58 shows a track construction where the rails are supported on concrete stringers *A*. The rails are connected together by steel cross-ties. This figure shows the method of paving brick up to a **T** rail, and Fig. 59 shows the method of bringing up the asphalt. The rail is a 60-pound **T**, 6 inches high, in 60-foot lengths. On straight track, it is laid on 24-pound steel ties, 3 feet between centers,

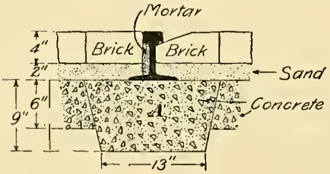


FIG. 58.

and on curves and special work, on 6 in. × 8 in. × 6 ft. 6 in. oak ties. All joints are broken or staggered and are carried on steel plates. In the construction shown in Fig. 59, the concrete comes above the foot of the rail; in order to get it well tamped under the rail and to avoid troubles incident to shrinkage on setting, the concrete was mixed with as little water as possible. The construction work, in brief, was as follows: After the old track was removed and the street dug out and rolled to grade, the new work was put in place, assembled, surfaced, lined, and gauged while temporarily supported on wooden blocks. The trenches for the concrete beams or stringers were then dug and the wooden formers placed in position. The 6-inch paving concrete was next laid, allowed to set for a day, and the formers removed to make way for the stringer, which was then installed. The concrete in the stringer was allowed to set for a week before a car was permitted to go over it. As the work was done in extremely hot weather and as the variation in length of the exposed rail was about 10 inches per 1,000 feet between night and day, the disastrous effects of this great expansion and contraction had to be prevented. This was done as follows: In the brick construction, as fast as the paving concrete was laid, the sand to be used as a paving bed was heaped over the rail and wet down; this was supplemented by turning V-shaped wooden troughs upside down over the whole.

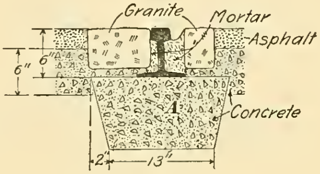


FIG. 59.

56. Fig. 60 shows a section of track construction in Detroit. It employs the best features of the two systems that formerly existed there and includes the concrete beam and the steel cross-tie (3-inch angle bars), used more as a tie-rod for keeping the rails to gauge than as a solid resting place for the rails. The concrete-beam work ordinarily goes to a depth of only 6 inches, but in soft spots it goes to a depth of 2 feet, if necessary. The concrete used in the beam is composed of 1 part Portland cement, 4 parts Louisville cement, 8 parts sand, and 16 parts broken stone, laid to a depth of 6 inches in a trench and brought up 1½ inches above the bottom of the ties.

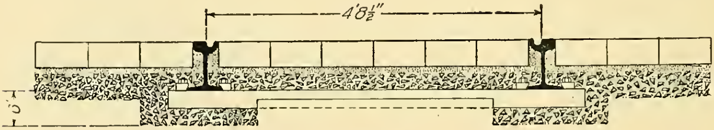


Fig. 60.

57. Fig. 61 is a section through a roadbed construction used in Chicago. One of the standard constructions is as follows: The street is excavated to grade to receive a layer of broken stone rolled to a depth of 6 inches; on this stone, 2 feet between centers, are laid the white oak ties 5 in. × 8 in. × 7 ft.; the rails, 85-pound girder section, are spiked to the ties and the space between ties is filled with broken stone or slag, which is well tamped to surface, and the rail lined. After the track is lined and surfaced, the stone is brought above the surface of the ties, where is placed a 1-inch layer of sand on which the paving blocks rest. The depth of the roadbed has lately been increased from 6 to 8 inches; this, together with the fact that 60-foot rails and cast-welded joints have been adopted, will go a long way towards lessening the trouble from poor joints. There are over 100,000 of these joints on a single system, and all the roads have their own cast-welding outfits. So much faith is there in the conductivity of the cast-welded joint that in some instances the use of bond wires has been discarded. The

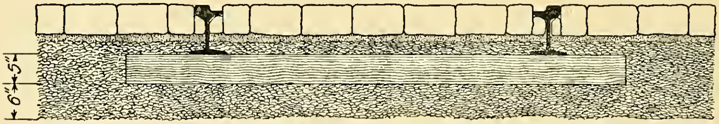


Fig. 61.

wisdom of this practice, however, is very doubtful. Unless the several lines of rail are well cross-bonded, the development of a single bad joint might materially affect the voltage at some remote part of the system.

58. Construction in Soft Subsoil.—Fig. 62 shows a style of track construction used in New Orleans. This city is very little above sea level, and most of the year the river is above the city. These facts, together with the fact that the subsoil is thoroughly permeated with holes made by the crawfish, make the city a floating land in the sense that wherever a hole is dug it immediately fills with water. It is not hard to conceive, then, how a roadbed constructed along the usual lines would soon give trouble. Several of the long lines in the city are built on neutral ground between two driveways, so that they are not subjected to the wear and tear of wagon traffic. This location of the tracks admits of the use of a T rail. Fig. 62 shows a section of the T-rail construction. The first step is to dig two trenches, one for each track, about 2 feet deep and 10 feet wide. The space between tracks and between the tracks and the roadways is all grass-grown, and as there is no traffic on it, no roadbed is needed. On the bottoms of the leveled trenches are laid lengthways 1¼-inch yellow-pine boards. This acts as the foundation for a layer of 1½-inch broken stone, on which the 6 in. × 8 in. × 8 ft. creosoted yellow-pine ties rest, 2 feet between centers. The space between the ties is filled partly with broken stone and partly with gravel that goes to the top of the ties. On top of the

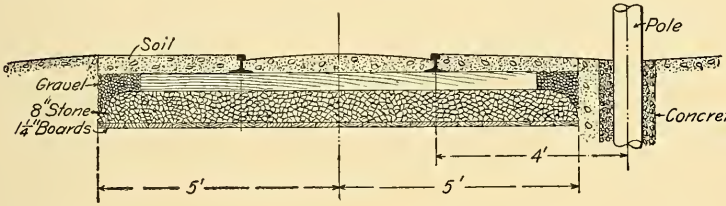


FIG. 62.

gravel is put a layer of soil in which grass is sown, so that a few months after the work is done the whole neutral ground is grass-grown—a feature that almost entirely does away with the clouds of dust ordinarily raised by a car in course of rapid transit. The plank construction on the bottom of the roadbed prevents the tendency of the track to sink into the soil and cause undulations in the surface line of the rail. The use of the T rail does not introduce complications at crossings, some of which are asphalt and others stone, because all wagon traffic being across the rail, no provision need be made for carriage wheels. At asphalt crossings the paving is brought right up to the head of the rail on both sides and the car-wheel flanges are allowed to cut their own flange ways. At stone-paved crossings the stone is flush with the rail head on the outside and on the inside a narrow space is left as a flange way. The rail used in this particular construction is $5\frac{3}{4}$ inches high, weighs 100 pounds to the yard, and is in 60-foot lengths. The joints are broken and are bonded with a No. 0000 B. & S. concealed bond.

59. Construction for Conduit Road.—There are no overhead wires allowed in the city of New York, so that all track work must be made to conform to the use of a slot to pass a cable grip or a trolley plow. The Third Avenue Railway affords an example of recent track work for a conduit road. The first step towards installing a conduit is to dig a trench about 3 feet deep and the width of the roadbed. The trench is rolled to grade and a 4-inch layer of concrete

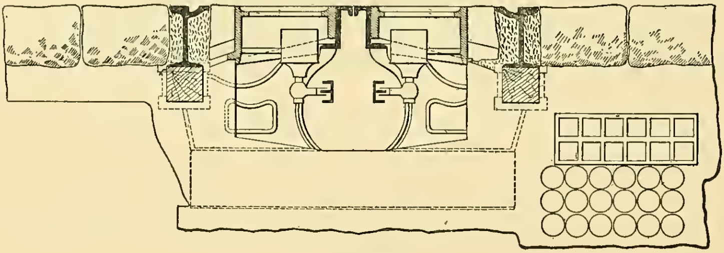


FIG. 63.

put on its bottom. Fig. 63 is a section through the construction in question. The 4-inch layer of concrete forms a surface on which to aline the ironwork, all of which is assembled before the main body of concrete is installed. The track rails and slot rails are supported on iron yokes spaced 3 feet apart and made up in three pieces, which is a new feature in such work. The three members are a steel **I** beam *A* and two cast-iron side pieces *B* (see *A* and *B*, Fig. 64) weighing about 125 pounds each. The yokes rest on the 4-inch concrete bottom, and the space between the yokes, the center of which space is the conduit proper, is filled with concrete that must be put in after the iron is in place, because the throat of the yoke dictates the general shape of the concrete part of the conduit. In order to shape the walls between the yokes, iron linings are used to support the concrete until it has set. These linings are made so that they can be freely drawn through the slot either way, and they are forced into position by means of a folding form operated by a lever. Fig. 64 gives a section through a plane that shows one of the yokes. The track rails are 9-inch grooved girders 107 pounds to the yard, in 60-foot lengths, laid on pine stringers. This stringer construction is a new feature in this class of work and is in accordance with the idea held by many engineers that a rigid support for the rails does not afford an easy riding track.

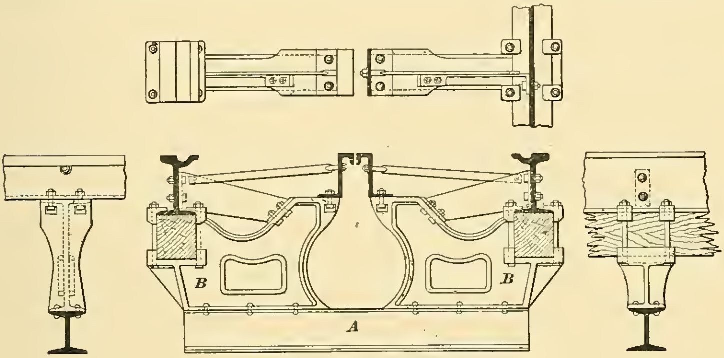


FIG. 64.

THIRD-RAIL CONSTRUCTION.

60. General Remarks.—The supply of current to cars has already been described in a general way in *Electric Railways*, Part 1. This method is coming largely into favor where the traffic is heavy. It has already been adopted on a number of elevated roads in New York, Brooklyn, Chicago, etc. It has also proved much superior to the overhead trolley for cross-country lines. It seems to be the only system adapted to the supply of heavy electric currents at normal voltages to meet the requirements of steam-road traffic conditions. In high-speed work, it is absolutely necessary to employ a rigid conductor that will not sag or sway under the influence of the moving contact. A good heavy steel rail seems to fulfil this condition to perfection. This rail, which gives the name to the system, is laid either between the two track rails or to one side and above one of them. The center-rail construction is safer in so far that it offers less opportunity for a person to step on it from the track rail, but this feature should not be relied on for safety. On the other hand, the side-rail construction is free from all liability to short-circuits due to a motor or brake rod or other part of the equipment coming loose in service and falling across the track rail and the third rail. The third rail is of much more assistance as a conductor than the ordinary trolley wire, because it has a large cross-section, and thus cuts down the amount of copper required for feed wires.

61. Examples of Third-Rail Construction.—The construction used on the Nantasket Beach road and described briefly in *Electric Railways*, Part 1, was one of the earliest third-rail systems installed in the United States. In this case, a third rail of special shape was used, but in the later roads it is nearly always of the ordinary **T** shape. In some cases these rails are insulated by supporting them on creosoted wooden blocks; in other cases they are supported on insulators made of "reconstructed granite," porcelain, or other insulating material. In Brooklyn, the third rail is outside of and above the track rail; sometimes on one side of the track and sometimes on the other, according to the surroundings. Each motor car carries four contact shoes, one on each corner of the car, and two of these shoes are always in a position to be active. The third rail is made up of all kinds and weights of old **T** rails, with the result that the joints are in some cases very uneven and have given a great deal of trouble by knocking off the contact shoes. The rails are held together by fish-plates and are bonded similar to the track rails. At branches, turnouts, cross-overs, sidings, etc., where it is necessary to break the line of the third rail, end pieces called **nosings** are fastened between the ends of the third rails and act to guide the shoes on the rail again. These nosings, which are of cast iron, are wider than the rail itself. They are bent down considerably on the ends and are renewable. They are found to give better service than bending the rail itself down to form a nosing. Where the line of the rail is broken in this way, the circuit is made continuous by means of a copper connecting cable. The third-rail line is supported at close and regular intervals on strong insulators made of reconstructed granite. The contact, or collecting, shoes are fastened to that part of the truck that is deflected least, and hence varies least in height when the load on the car changes. The shoe beam must, therefore, be hung from a point that is not responsive to the action of the main-truck springs. On account of this comparatively rigid suspension of the shoe beam, with its contact shoes, it is absolutely essential that the surface line of the third rail be true and level and that the tops of the rails at joints be exactly flush; if they are not, as experience has proved, there will be no end of trouble from losing contact shoes. As a factor of safety, it is well to make the slotted links, by means of which the steel shoes are hung from the steel rack, of gray cast iron, so that in case the passage of the shoe along the rail becomes obstructed for any reason, the links will give away and the rack and beam will be spared.

62. Fig. 65 shows the style of contact shoe used on the Albany and Hudson third-rail road. It will be noticed

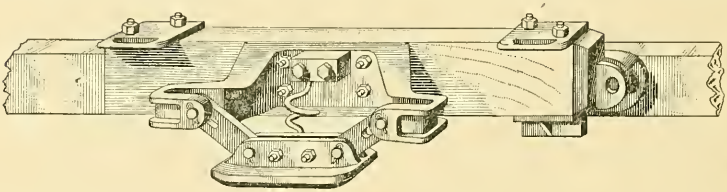


FIG. 65.

that it is very similar in general design to that described in *Electric Railways*, Part 1, as used on the Nantasket Beach road. Fig. 66 shows the style of support used for the third rail on the Albany and Hudson road. Every fifth tie is extended to one side so as to take the third-rail support, which consists of a wooden block *A*, to which is attached the malleable cast-iron top *B*. The third rail is held by keys under the ears *c*, *c*. This road uses an 80-pound **T** rail for the third-rail conductor.

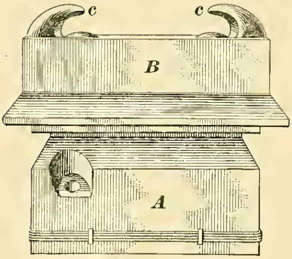


FIG. 66.

63. Snow and Ice on Third Rail.—Snow and ice often cause a great deal of annoyance in connection with the operation of third-rail roads. There are times when the third rail gets so thoroughly coated or glazed with a thin layer of ice that the trains have been unable to run at all. The ice is such a poor conductor that the current will not go through it as thin as it is, and yet it is so smooth and hard that no mechanical device outside of a milling machine will effectively remove it from the surface of the rail. Several devices have been tried for keeping the rail clear of ice; among the most effective may be mentioned a free use of oil to keep the ice from forming and a free use of brine to remove the ice if it is already there. Both of these schemes have been only partially successful, but have done good work in the absence of better means. It has been the practice to apply the oil by means of an ordinary swab in the hands of men placed at intervals along the line; the salt water can be squirted on to the rail by means of a small rubber hose, leading from a tank placed on the rear end of a train or car especially adapted to do the work. The oil cannot be so applied, because the problem of getting the liquid, whatever it may be, on the rail and not in the street below has given a great deal of trouble.

64. Third-Rail Precautions.—The ordinary third rail cannot, of course, be used for surface roads in cities. Its use for city work is, therefore, confined to elevated roads. In densely populated parts, the third rail should be split up into a number of sections, and the feeders supplying these sections should be provided with switches, so that in case of fire, either on a car or in nearby buildings, the current may be cut off. In case of fire, the live third rail is very often a source of hindrance to the firemen in the performance of their duties, and in some cases is even a source of danger. When a fire, caused by some abnormal condition of the circuit, occurs on a motor car, the only way to break the current, if the feeder switch cannot be reached and the circuit-breaker is out of order, is to lift the contact shoes from the rail, and this is not an easy thing to do, unless there are special means provided for the purpose. Every motor car should be provided with a pair of wooden paddles with handles about 3 feet long. To cut off the current, it is only necessary to shove one of these paddles in between the third rail and each of the two active contact shoes.

ELECTRIC RAILWAYS.

(PART 4.)

CALCULATION OF FEEDERS.

1. In the transmission of current for electric railways, as in other cases of electric transmission, we are usually limited to a certain amount of loss or drop in the line. If the loss is large, we can use a comparatively high-resistance line with a corresponding small amount of copper. A large line drop, however, means a low voltage at the cars unless the voltage at the station is automatically increased as the load increases. Low line voltage makes it hard for the cars to maintain their schedule and always gives rise to trouble with the motors, to say nothing of the actual cost of the power wasted in the line. It does not pay, therefore, to allow the line loss to become excessive, and the feeders must be designed to keep the drop within the specified amount. The average percentage loss may vary greatly. It is seldom that the drop is less than 10 per cent. (50 volts), and in a great many cases it runs much higher than this.

2. The weight of the rail is fixed by traffic considerations, so that an approximate estimate of what the drop in the return circuit will be can be formed at the outset. The balance of the drop will then give that allowed for the feeders, and they should be designed to conform to this as nearly as possible. Feeders designed under this condition seldom fail to fulfil the requirements of the average drop.

There is a great difference between the maximum and average loads in the stations, and the smaller the station, the greater the difference is liable to be. For this reason, the average drop and maximum drop may be widely different. Take a case where the road operates only two or three cars and the load fluctuates between zero and the maximum several times in perhaps a minute. Before the size can be assigned to the feeders, the average load that each feeder has to look after must be approximately known or ascertained. In doing this, it is very convenient to divide the line into sections, assign to each section the load that probably will be on it, and proportion the feeders accordingly. Incidental to this method, a certain maximum drop or average drop must be assigned to each of the feeders, so that the operation of the cars on all sections of the line will be practicable under all ordinary conditions.

3. Estimation of Load.—In assigning the probable loads to the several sections, some knowledge must be had of the number of cars that are to be run and of their headway or distribution. A knowledge of the weight of the car and its equipment is also necessary in order to determine the current that the car will take under average conditions. As far as the *relative* sizes of the feeders and their points of feeding are concerned, any convenient unit of current per car can be selected, but in order to determine the *actual* size of the feeder in order to keep the drop within the specified amount, its actual load in amperes must be at least approximately known.

4. Rules for obtaining the current required under different conditions have already been given in *Electric Railways*, Part 2. The current, if supplied at a fixed voltage, is almost, if not quite, proportional to the speed of the car. Not only the variable speed at which the cars will run, but other things will tend to make the current required per ton a variable quantity, so that unless the road is already in operation and the average current consumption per car is known or can be found out, it will be necessary to know the style of car, motors, etc., and the conditions under which they are to be run, or to take this value from the experience of others. Let us assume a 24-foot car body equipped with 37-horsepower motors and call the average current per car throughout the day 20 amperes. This may strike one as a very low value when compared to the current called for when the two motors run at their rated output, but it must be borne in mind that a great deal of the time the car takes no current at all, for it may be coasting or standing still with the power off. The value of the average current per car is obtained by taking current readings on the car at regular intervals throughout several characteristic trips. The closer these readings are taken together, the more accurate will be the result. These current values are all added together and divided by the number of readings, and this gives the average of the current during the time covered by the test. This test should be made at a number of different hours during the day and the average value of all these average results taken. This final average is the load to be assigned to each of the several cars; this load multiplied by the number of cars to be run gives the average load of the whole road, or the load that the feeders will be called on to handle. The car referred to above is of medium size. Large double-truck cars would take a much larger current, the average probably being from 50 to 75 amperes, depending on the grades, etc.

5. Example of Feeder Calculation.—On account of its mechanical strength, low cost of maintenance, and good conductivity, the trolley wire in the following calculations will be assumed to be No. 00 hard-drawn copper having a resistance of about .08 ohm per 1,000 feet. This value covers the average conditions of temperature.

Fig. 1 shows the layout of a road that we will assume to be 5 miles long. The system is fed from a power station at one end of the line and operates ten cars using on an average 20 amperes of current per car, making a total of 200 amperes. It is prescribed that the total load *concentrated at the end of the line* shall not produce a drop of over 100 volts. If the trolley wire is No. 00, what must be the size of the feeder $B\ A$?

The road is single track, so that there is available the conductivity of two lines of rails in the return circuit. These rails will be 5 miles long, and at .0111 ohm per 1,000 feet, including bonds, will measure .0586 ohm per mile; 5 miles of track will, therefore, measure $.0586 \times 5 = .293$ ohm,

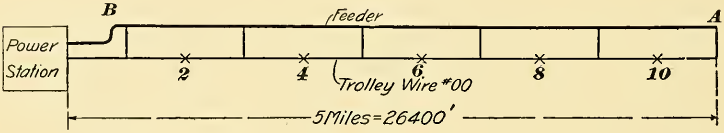


FIG. 1.

which resistance, carrying a current of 200 amperes, will cause a drop of $200 \times .293 = 58.6$ volts, leaving a drop of $100 - 58.6 = 41.4$ volts to take place in the trolley wire and feeder. If we assume that the conductivity of the copper in the trolley wire is the same as that in the feed wire, we may use the formula

$$\text{Circular mils} = \frac{10.8 \times L \times C}{e}, \qquad \textbf{(1.)}$$

where L = length of wire in feet through which the current C is delivered;
C = current supplied;
e = drop in volts.

The number of circular mils given by this formula will be the combined cross-section of the trolley and feeder, because these two wires are tied together in parallel throughout their length. In this case, $L = 26{,}400$ feet, $C = 200$ amperes, $e = 41.4$ volts; hence,

$$\text{Circular mils} = \frac{10.8 \times 26{,}400 \times 200}{41.4} = 1{,}377{,}400, \text{ nearly.}$$

The trolley wire is No. 00 and has an area of cross-section of 133,079 circular mils, as will be seen by referring to the wire table in *Electric Transmission*, Part 1. Deducting this from the total cross-section called for, leaves $1,377,400 - 133,079 = 1,244,321$. This will be a very large feeder, and 5 miles of it would be very expensive.

6. Another Solution of the Same Problem.—In the above we assumed that the trolley wire was of practically the same quality of copper as the feeder. This makes the solution simple and accurate enough for all practical purposes, because the trolley wire is small compared with the feeder. We will assume that the hard-drawn trolley wire has a resistance of .08 ohm per 1,000 feet, which is somewhat higher than the resistance of a soft-copper wire of the same size, and work out the example by a different method in order to compare results.

The drop in the overhead system is limited to 41.4 volts, and as the current is 200 amperes, the resistance must be $R = \frac{41.4}{200} = .207$ ohm. The total resistance of the trolley wire itself is $.08 \times \frac{26400}{1000} = 2.112$ ohms. The feeder must then be of such a size that when it is connected in parallel with a resistance of 2.112 ohms, it will bring the combined resistance of the two down to .207 ohm. If R is the combined resistance of the two resistances R_1 and R_2 connected in parallel, then

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}.$$

Since we know the values of R and R_1, it is necessary to solve the above equation for R_2. The above equation may be transposed as follows:

$$\frac{1}{R} - \frac{1}{R_1} = \frac{1}{R_2}.$$

This equation, by reducing the left-hand side to a common denominator and then inverting the fractions, may be transformed so as to give

$$R_2 = \frac{R \times R_1}{R_1 - R}.$$

Since $R = .207$ and $R_1 = 2.112$, we get, by substituting these values in the last expression,

$$R_2 = \frac{.207 \times 2.112}{2.112 - .207} = .229.$$

Five miles of the feeder must then measure only .229 ohm. We have the general formula

$$R = \frac{10.8 \times L}{\text{cir. mils}},$$

where R = resistance of a copper wire;
L = length of the wire in feet;
cir. mils = area of cross-section of the wire in circular mils.

Or, we may write

$$\text{Circular mils} = \frac{10.8 \times L}{R}, \qquad \textbf{(2.)}$$

and in this case

$$\text{Circular mils} = \frac{10.8 \times 26{,}400}{.229} = 1{,}245{,}065.$$

This, it will be noticed, is a slightly larger cross-section than was called for by the previous method, but the difference is not of practical importance for a cable of such large size. Formula **1** is accurate enough for general use and gives the simplest means of getting at the required feeder cross-section.

7. The student should note particularly that in working the above example a fair value for the track resistance was assumed and the drop in the track circuit then estimated. This drop was subtracted from the total drop, thus giving the value e used in formula **1.** Formula **1** does not, therefore, in itself take the track resistance into account.

In the last example it was found that a very large feeder was needed to meet the requirements. Of course, these requirements were severe, because the drop was not to exceed 100 volts when all the cars were bunched at the end of the line. In most cases the cars would be moving along over different sections of the line, and this would lessen the drop on the system, because some of the cars would be comparatively near the station. At the same time, conditions arise where the cars may all be bunched at the end. In this particular case, therefore, it would be well to raise the voltage to 600 at full load at the station, either by using a very heavily overcompounded generator or by using a booster.

8. Example With Power House in Middle of Line.—If the power house were situated at the middle of the line, the amount of copper required would be very much less, as will be easily seen by referring to Fig. 2. The limiting condition is the same as before; that is, the drop from S to A or B must not exceed 100 volts when all the cars are concentrated at either A or B. If the cars are bunched at either A or B, 200 amperes must be transmitted through $2\frac{1}{2}$ miles of track and feeder. Taking the track resistance as .0111 ohm per 1,000 feet, the resistance of $2\frac{1}{2}$ miles of track will be $\frac{13200}{1000} \times .0111 = .1465$ ohm. The drop in the track part of the circuit will, therefore, be $.1465 \times 200 = 29.3$ volts. This leaves a drop of $100 - 29.3 = 70.7$ volts to take place in the feeder and trolley wire. The length of feeder and trolley wire is $2\frac{1}{2}$ miles; hence, by applying formula **1**, we have the combined cross-section of the two,

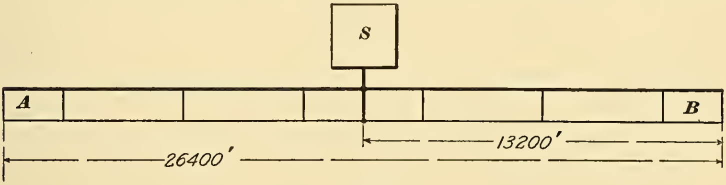


FIG. 2.

$$\text{Circular mils} = \frac{10.8 \times 13,200 \times 200}{70.7} = 403,281.$$

The trolley wire supplies 133,079 circular mils of this cross-section; hence, the cross-section of feeder required is $403,281 - 133,079 = 270,202$. It is easily seen that placing the power house near the middle of the line results in a very large reduction in the amount of copper required.

9. It may be of interest, in passing, to see what the effect would be in the above two cases if the feeder were done away with altogether and the trolley wire increased in size to No. 0000. In the first case, 200 amperes would be transmitted over 5 miles of trolley wire. No. 0000 trolley wire has a resistance of about .05 ohm per 1,000 feet. Five miles of No. 0000 wire would, therefore, measure 1.32 ohms. A current of 200 amperes through this resistance would cause a drop of $200 \times 1.32 = 264$ volts, which, even if the power-house voltage were maintained at 600, would leave only 336 volts for the operation of the cars, to say nothing of the drop in the track part of the circuit, and this would not be sufficient for satisfactory operation.

In the second case, with the power house at the middle of the line, the drop in the trolley wire would be only one-half as great, because the wire would be only one-half as long, but even then the drop would amount to 132 volts in the trolley wire or $132 + 29.3 = 161.3$ volts altogether. If the station voltage were the standard 500 volts, the pressure at the cars would then be $500 - 161.3 = 338.7$ volts, which would not be sufficient to run the cars on schedule time. If, however, the power-house voltage could be raised to 600 at full load, a pressure of 438.7 volts would be obtained at the cars. This voltage, while not as economical from the car-operation point of view as it should be, is entirely practicable, as there are very few roads where the voltage under conditions of concentrated end load is as high as 475 volts.

10. Effect of Distributed Load.—So far we have worked out these feeder problems on the assumption that the load was bunched at one end. This is a condition that sometimes arises in practice, but it can hardly be looked on as the ordinary operating condition. In most cases we have a number of cars spaced at fairly regular intervals along the line, each car moving at an approximately uniform rate. The result of this is that current is taken off at a number of points that are continually shifting along the line. The load is practically uniformly distributed and there is a gradual falling off in current from the station to the end of the line. For example, suppose *A B*, Fig. 3, represents a stretch of line that supplies six uniformly spaced cars moving at a uniform speed and taking 20 amperes per car. On account of the uniform movement and even spacing, the current will decrease gradually from 120 amperes at the station to zero at the end *B*. We may represent the falling off in the current by the line *C B*. The drop between *A* and *B* will, therefore, be found by multiplying the average current in *A B* by the resistance. The average current is evidently one-half the station current, or 60 amperes; hence, if the resistance of *A B* were, say, $\frac{1}{2}$ ohm, the drop between *A* and *B* would be 30 volts. If the whole load were

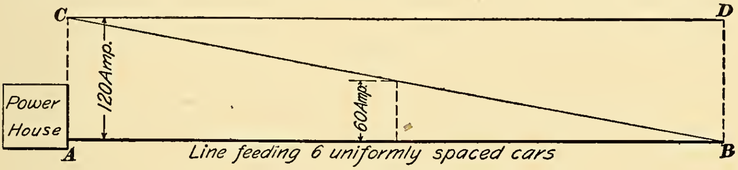


FIG. 3.

bunched at *B*, the current would be 120 amperes throughout the whole length, as represented by the line *C D*, and the average current throughout the length would be the same as the current at the station; hence, the drop would be $120 \times \frac{1}{2} = 60$ volts. From the above, it may be stated that *for a given line wire and a given amount of current transmitted, the drop with a uniformly distributed load is one-half that with a concentrated end load.* In other words, if we are making calculations relating to a distributed load and consider the whole length of line in our calculations, we must take the current as one-half the actual current supplied to all the cars, because the current falls off as previously described from the station, or feeding point, to the end of the line.

Another and perhaps a better way of considering a distributed load is to look on it as if the whole load were concentrated at the middle of the line and work out the problem as if the whole current were transmitted over half the line.

11. Example of Calculations for Distributed Load. Taking the road shown in Fig. 1, find what size of feeder will be required when the load is distributed and also when the drop to the end of the line is limited to, say, 50 volts. Here 50 volts has been taken as the allowable drop, as this is a common value aimed at in practice.

There are ten cars, each taking 20 amperes and uniformly spaced; the whole load of 200 amperes may be considered as being concentrated at the middle of the line, or it may be considered that an average current of 100 amperes is transmitted over the whole line. In order to be definite, we will choose the former and simply work the problem as if 200 amperes had to be transmitted through $2\frac{1}{2}$ miles of feeder and $2\frac{1}{2}$ miles of track with a drop of 50 volts. The track resistance was found to be .0586 ohm per mile, so that the resistance of $2\frac{1}{2}$ miles of track will be $.0586 \times 2.5 = .1465$, and the drop in the track $= .1465 \times 200 = 29.3$ volts. This leaves $50 - 29.3 = 20.7$ volts drop for the feeder and trolley. Then the combined cross-section of the feeder and trolley will be

$$\text{Circular mils} = \frac{10.8 \times 13{,}200 \times 200}{20.7} = 1{,}377{,}400.$$

It will be noticed that this combined cross-section is the same as that found necessary to supply an end load with a drop of 100 volts. In other words, with the same amount of line copper a uniformly distributed load will produce only one-half the drop that a bunched end load will cause, or if the drop is kept the same in both cases, the amount of copper required for the distributed load will be only one-half that called for by the concentrated load.

With the system shown in Fig. 1 and a combined cross-section of feeder and trolley of 1,377,400 circular mils, there will be a drop of 50 volts when the cars are uniformly distributed, and if for any reason it becomes necessary to bunch the cars all at one end, the drop will become 100 volts.

The method of working out the case shown in Fig. 2 will be the same as the above except that the current supplied each side of the station will be only 100 amperes, because the load is uniformly distributed and one-half the cars will be on each side. Also, this 100 amperes will be considered as concentrated at the middle of the 13,200 feet. This will require much less copper than when the load is concentrated at either end. In the above, the student must not forget that although we have considered the load as bunched at the middle of the line, the feeder runs the whole length, as indicated in the figures.

12. Example of Calculations for a Loop Line.—Fig. 4 represents a so-called **loop line** that runs down one street and comes up at the next street parallel to it. It is a modified form of the **belt line** that is supposed to encircle the business part of the city, but it differs from a belt line in that, since the parallel lines are in neighboring parallel streets, the power house can, without great sacrifice of economy, be placed to one side of the area enclosed by the system, instead of being placed within this area.

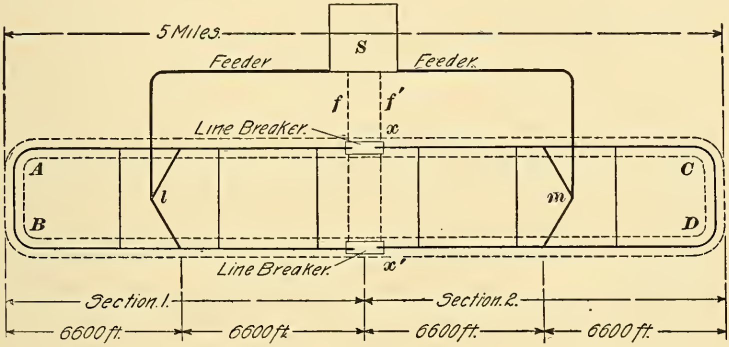


FIG. 4.

In Fig. 4, *A C* is the street that the cars go up, *D B* the street on which they return. It must be noted that the area enclosed by the two tracks is very long in comparison to its width. The width between the streets is exaggerated in Fig. 4 in order to make the arrangement clearer. As a matter of fact, the loop would be very long and narrow.

The full line indicates the path of the trolley wire and the dotted lines that of the track. The two trolley wires are tied together at intervals so as to equalize the current between them; the rails are likewise tied together. The two heavy full lines running to the right and left of the power house indicate the two feeders that are tapped into both trolley wires at the middle of the sections. It is assumed that the trolley line is divided into two sections by the line breakers x, x' and that each feeder feeds in at the middle point of the sections. Since the two sections are independent and since each is supplied by its own feeder, we can calculate one of the feeders; the other will be the same, because the road is symmetrical. Since the cars are supposed to be uniformly distributed, the load on each section may be considered as being concentrated at the middle of that section, that is, in this case, where the feeders are attached. Taking each section by itself, it will be seen that this problem is similar in many ways to the last one worked out. Let us assume that the specifications require that the drop from the station to the feeding-in points l, m shall not exceed 50 volts when the cars are taking their average current and are uniformly distributed. A total of ten cars is operated and each car takes 20 amperes. The number of cars on each of the two sections will, therefore, be five and each feeder will have to supply 100 amperes. Since the trolley wire is fed from the middle point of each section and there are no feeders on the end of the section, there will always be more or less drop in the trolley wire itself. This drop will not, however, amount to much, as the distance from l to the end of the line or to the line breakers is short and there cannot be more than two cars in any one of these sections of trolley wire at the same time. The length of a section is $2\frac{1}{2}$ miles, or 13,200 feet; a half section is 6,600 feet, and a quarter section is 3,300 feet. For the present we will omit any consideration of the loss in the quarter section of double trolley wire and simply conform to the requirements of the limiting condition. The resistance through which the drop of 50 volts is to take place is that of four lines of single rail well bonded together and the feed wire, both of which are $1\frac{1}{4}$ miles long. The current at which this drop will take place is 100 amperes. The resistance of $1\frac{1}{4}$ miles (6,600 feet) of double track is $6.6 \times .0056 = .037$ ohm, because the resistance of 1,000 feet of single 80-pound rail is .0223 ohm, so that the resistance of 1,000 ft. of single track, four rails in multiple, is $.0223 \div 4 = .0056$ ohm. A current of 100 amperes through a resistance of .037 ohm causes a drop of $100 \times .037 = 3.7$ volts. The total drop is limited to 50 volts, so that the drop in the feeders must be $50 - 3.7 = 46.3$ volts. The length of the feeder is 6,600 feet, so that we have

$$\text{Circular mils} = \frac{10.8 \times 6{,}600 \times 100}{46.3} = 154{,}000, \text{ nearly.}$$

A No. 000 B. & S. wire has a cross-section of 167,805 circular mils, so this size would probably be used, and $2\frac{1}{2}$ miles of this feeder would be needed to equip the road.

13. In the layout shown in Fig. 4, the trolley wires are not fed on the ends at all, and should the five cars on a section become bunched at one end there would be quite a drop in voltage in the trolley wire in addition to the drop in the feeder. Suppose all cars on section *2* to be bunched at C; a total current of 100 amperes will have to be supplied to these cars, and this current will have to flow through $1\frac{1}{4}$ miles of double trolley wire and back to the power house through the double track. The drop in the $1\frac{1}{4}$ mile of double track from m to C will be very small, so we will confine our attention to the drop in the trolley wire. Taking the resistance of the trolley wire as .08 ohm per 1,000 feet, $1\frac{1}{4}$ miles will have a resistance of $\frac{6600}{1000} \times .08 = .52$ ohm, approximately. There are, however, two trolley wires in multiple, so that the resistance from m to C will be .26 ohm; and, with a current of 100 amperes, the drop will be $100 \times .26 = 26$ volts. This drop, it must be remembered, will only occur under the extreme condition where the five cars on a section are all bunched at one end. Under normal conditions, the drop in the trolley will not be more than one-quarter of this amount, or about 6.5 volts. This, together with the 50 volts loss allowed in the feeding system, will make the total average drop in the overhead system about 56.5 volts. If the voltage at the station is maintained at 500 volts, this will leave a pressure of 443.5 volts at the cars. However, most railway generators are overcompounded to give a rise of at least 10 per cent. in voltage from no load to full load, and with a machine of this kind the voltage at the cars will drop but little under 500.

Another way to allow for the trolley-wire loss is to make the feeder a little larger. In this case, increasing the size to No. 0000 will be sufficient, but unless there is a prospect of some future extension to the road or an increase in the number of cars, the best thing to do is to run the dynamos at a little higher voltage.

14. In Fig. 4, suppose we connect two feeders *f*, *f'*, indicated by the dotted lines, one to each section, directly from the power house, and see what effect this will have on the voltage supplied to the cars. In practice, it will cost but little to do this, because these feeders will be very short. Consider one of the sections, say, section *1*. It is fed by the regular feeder previously calculated, and, in addition, the feeder *f* runs out directly from the power house and is tapped on the trolley wire at the line breaker. We will find what the drop would be under the most unfavorable conditions, that is, with the five cars on the section bunched at *A*. The whole current, 100 amperes, will have to return to the station through 2½ miles of double track. In the overhead work there will be 1¼ miles of feed wire, and in multiple with this will be the two trolley wires extending back to the station, because the connection of the feeder *f* puts the trolley wires in multiple with the regular feeder. Up to the point *l*, therefore, we have the feeder and the two trolley wires in multiple to carry the current. Beyond *l*, to the end of the line, the current is carried by the two trolley wires alone.

The resistance of $2\frac{1}{2}$ miles of double track, assuming the resistance per 1,000 feet to be .0056 as before, will be .074 ohm. The resistance of $1\frac{1}{4}$ miles of two No. 00 trolley wires in multiple, if a single No. 00 hard-drawn copper wire measures .08 ohm per 1,000 feet, will be

$$\frac{.08}{1{,}000} \times 5{,}280 \times 1\tfrac{1}{4} \times \tfrac{1}{2} = .26 \text{ ohm.}$$

The resistance of $1\frac{1}{4}$ miles of No. 000 feeder wire is about .41 ohm, and this in parallel with the resistance of $1\frac{1}{4}$ miles of double trolley gives the resistance from the station to the point *l* as

$$\frac{.26 \times .41}{.26 + .41} = .16 \text{ ohm.}$$

The total resistance to the end of the line and return will then be $.074 + .26 + .16 = .494$ ohm. This will give a drop of 49.4 volts with a current of 100 amperes. It is thus seen that where the load is bunched at the far end, the addition of the feeders at the station does not improve the drop very much, because without the use of these feeders the drop would be about 56.5 volts. If, however, the load should become bunched at, say, *l*, the point where the feeder taps in, the track resistance will be .037, and the combined resistance of the feeder and trolley wires .16, making a total resistance of .197 ohm, and the drop will be only 19.7 volts as against 46.3 volts if the feeder alone were used. If the load were concentrated at the power-station end of the section, there would be little or no resistance in the circuit, save that of the tap wire and the ground-connection wire, so it is safe to say that the loss caused by a current of 100 amperes would not at this point be more than 5 volts. It is easily seen, then, that the effect of tapping the feeder in at the power-station end of the section and thereby getting the full benefit of the conductivity of the trolley wire is a good move, as it results in lowering the voltage loss due to resistance. The power-house taps, as well as the line feeder, must be provided with feeder switches, so that the current may be cut off any section desired.

15. Loop Line Supplied by Four Feeders.—In the last illustration it was shown that the introduction of taps, or short feeders running into the power house, had the effect of keeping up the voltage on all parts of the line to some extent, but that the effect was most pronounced on the part of the line comparatively near the power house. By adopting a little different method of feeding, we can keep the voltage more uniform at all points. In Fig. 4, it will be noticed that the feeding-in points are, as it were, lopsided. In other words, most of the feeding-in is done on the half of the section nearest the power house. We will, therefore, extend the feeders as shown in Fig. 5, and have the two points where the current is fed in 6,600 feet apart as before, but situated 3,300 feet, or $\frac{1}{4}$ section, from each end. The point where feeder *1* taps in will then be 9,900 feet from the station, and the point where feeder *2* taps in 3,300 feet from the station. The length of trolley wire projecting beyond the taps on both ends will be 3,300 feet.

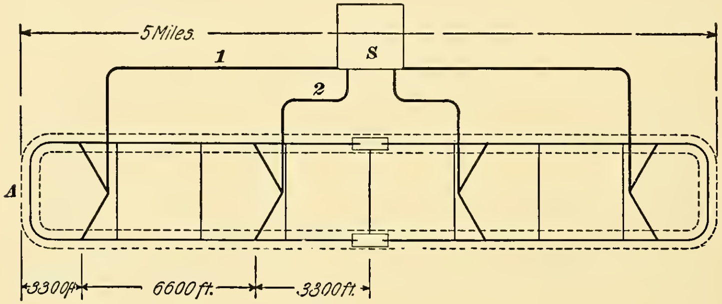


FIG. 5.

As before, we will first see what the drop will be if the five cars are bunched at the end *A*. The current will have to come back through 13,200 feet of double track, which, as before calculated, has a resistance of .074 ohm. The flow of the current in the overhead work is somewhat more complex. In the first place, there are 3,300 feet of double trolley wire on the far end of the line; this will have a resistance of $.08 \times \frac{1}{2}$

$\times \frac{3300}{1000} = .13$ ohm. Next, the short feeder *2*, which we will suppose is the same size as *1*, is 3,300 feet long and is in series with 6,600 feet of double No. 00 trolley wire, and these two in series are in multiple with the long feeder *1*. No. 000 wire has a resistance of about .062 ohm per 1,000 feet. Feeder *1* is 9,900 feet long and has a resistance of $9.9 \times .062 = .614$ ohm. The resistance of the short feeder and double trolley wire combined is $3.3 \times .062 + \frac{6.6 \times .08}{2} = .469$ ohm. This is in multiple with the feeder whose resistance is .614 ohm; hence, the combined resistance of the two will be

$$\frac{R_1 \times R_2}{R_1 + R_2} = \frac{.469 \times .614}{.469 + .614} = .26 \text{ ohm.}$$

The total resistance from the power house to the end of the line and back again will then be $.13 + .26 + .074 = .464$ ohm, and with a current of 100 amperes the drop will be 46.4 volts. This is better than was obtained with the first layout considered in connection with Fig. 4, where there was 50 volts drop to the feeding-in point and 26 volts more through the trolley wire.

16. Next, suppose the whole load to be located just at the long feeder tap. In this case the resistance is the same as before less the resistance of 3,300 feet of double trolley wire on the end and 3,300 feet of track. The resistance of 9,900 feet of rail return is $9.9 \times .0056 = .055$ ohm, nearly. The whole resistance will then be $.055 + .26 = .315$ ohm, and the drop will amount to $.315 \times 100 = 31.5$ volts.

17. If the whole load is located at a point midway between the two feeder taps, each feeder will have the same length of trolley wire in series with it and the two sets will be in multiple; also, there will be 6,600 feet of track in the circuit. The resistance of the long feeder and its 3,300 feet of double trolley will be $.614 + .13 = .744$ ohm. The resistance of the short feeder and its 3,300 feet of trolley wire will be $.205 + .13 = .335$ ohm, and the resistance of the two sets in multiple will be $\frac{.335 \times .744}{.335 + .744} = .231$ ohm, nearly. The resistance of the track will be .037 ohm, thus giving a total resistance of $.231 + .037 = .268$ ohm for the whole circuit. This will cause a drop of 26.8 volts with the load concentrated between the taps.

18. If the load is just at the end of the short feeder tap, the circuit resistance will be distributed as follows: There will be 3,300 feet of rail return, and the long feeder will be in series with 6,600 feet of double trolley wire, and the two together will be in multiple with the short feeder. The working out of the drop in this case is left as an exercise for the student. It is in the neighborhood of 18 volts.

If the load is somewhere near the line breaker in front of the station, the loss is increased by 13 volts on account of the trolley wire between the tap and the line breaker. On the other hand, the drop will be decreased by nearly 2 volts, because there is no track included in the circuit with the load in front of the station. The net increase will therefore be about 11 volts.

The general effect of using the two feeders is to equalize the voltage on the system, thus enabling the cars to maintain a uniform speed.

The above simple examples have been selected to show the student how ordinary feeder calculations may be made. They do not, of course, cover the whole field of feeder design, but the principles and methods of calculating here given should enable one who is at all inclined to look into the subject to investigate and possibly improve the working conditions on a road of moderate size.

19. Comparison Between Track Resistance and Overhead Resistance.—As already stated, it is difficult to estimate the resistance of the track closely even if the weight of the rails is known, because the bond resistance is uncertain. Formerly, in making line calculations, it was assumed that the track circuit had no resistance, but, as previously pointed out, this was far from the truth. Very often the resistance of the track circuit is taken as about $\frac{1}{4}$ that of the overhead circuit, but it is evident that no general relation between the two can be given, because, in the first place, the size of the rails may vary in different cases, and in the second place, the amount of copper put in the overhead line varies within wide limits, depending on the nature of the traffic and the amount of loss allowed.

The ordinary formula that we have been using for making feeder calculations,

$$\text{Circular mils} = \frac{10.8 \times L \times C}{e},$$

applies, as it stands, to the copper part of the circuit only, and the length L refers to the length of the copper part of the circuit through which the current C flows. If we know the relative amount of resistance in the track as compared with that in the line, we can modify this formula so as to take account of the resistance of the rail return. A formula of this kind is very convenient for making approximate calculations. According to Dr. Louis Bell, a constant of 14.4 instead of 10.8 will allow approximately for the resistance of the track return, thus giving the formula

$$\text{Circular mils} = \frac{14.4 \times L \times C}{e}. \qquad \textbf{(3.)}$$

This means that under average conditions of load and track-return resistance *the cross-section in circular mils of a feeder necessary to deliver a current C with a drop e is equal to 14.4 times the length of the feeder in feet times the current divided by the volts drop.*

It must not be forgotten that this formula is not exact in all cases; it merely represents average conditions. The constant appearing in the formula is found to lie between 14 and 15 on the great majority of roads as ordinarily built.

20. In order to further illustrate feeder calculations, we will work out the case of a small road and at the same time make use of formula **3** in order to illustrate its application.

EXAMPLE.—Fig. 6 shows the layout of a single-track road operating nine cars, which are spaced fairly evenly along the line. The road is divided into two sections by means of a line breaker. Each section is provided with a No. 000 main, as indicated, and these mains are fed by two feeders *1* and *2* running from the power station. The drop under average conditions is to be limited to 50 volts. Each car takes an average current of 20 amperes.

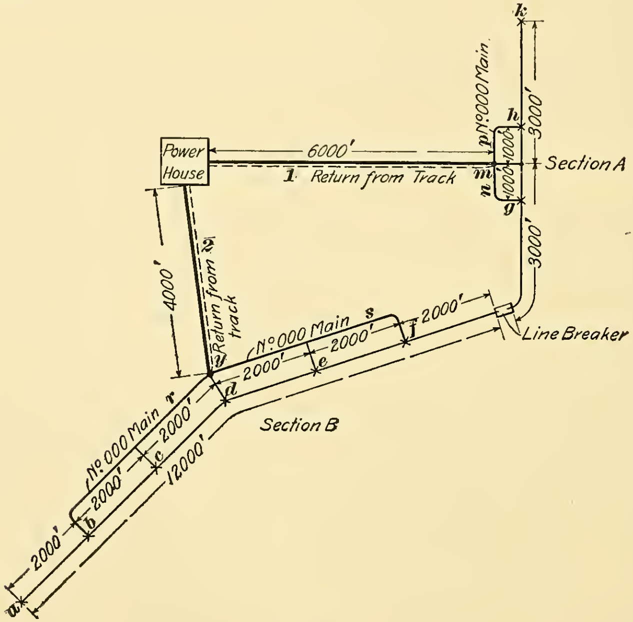


FIG. 6.

SOLUTION.—Since the cars are equally spaced and constantly shifting in position, the drop will vary somewhat, depending on the position of the cars. In order to make things definite, we will assume that the cars are located as shown by the crosses. This will represent a fair average condition, and the drop for other positions will not be greatly different unless the cars become bunched in some particular spot. If we design the feeders so that the drop from the power house to cars *a* and *k* shall not exceed 50 volts, it is evident that the drop to the other cars will fall under the prescribed 50 volts, because cars *a* and *k* are the most distant from the station. No track resistance is specified, so we will make use of formula 3 in estimating the drop in those parts of the circuit that include a track return. We will first take section *A* and determine the size of feeder *1*.

Section A.—The road operates nine cars and is 18,000 feet in length; hence, there will be one car for every 2,000 feet. Section *A* will have three cars and the current supplied by feeder *1* will be 60 amperes. The size of the trolley wire and its distributing main is fixed, so that we must first determine the drop in this part and then see what is left for the drop in the outgoing and return feeders. It is easily seen that return feeders from the track must be used, because the power house is some distance from the track and the ground cannot be depended on to carry the current. The return feeders may be strung either on poles or placed underground. We will first determine the drop from h to k. To do this we have the formula

$$\text{Circular mils} = \frac{14.4 \times L \times C}{e}.$$

In this case, however, we know the number of circular mils in the cross-section of the trolley wire and wish to find e; so, transposing the formula, it becomes

$$\text{Drop } e = \frac{14.4 \times L \times C}{\text{cir. mils}}.$$

In this case, L (distance from h to k) = 2,000 feet, $C = 20$ amperes, and the circular mils of No. 00 wire = about 133,000;

hence, $$\text{Drop } e = \frac{14.4 \times 2{,}000 \times 20}{133{,}000} = 4.3 \text{ volts.}$$

The drop from the feeding-in point m to the point h is next calculated. The cross-section of the wire carrying the current is that of the main (No. 000) plus that of the trolley (No. 00). The total number of circular mils is then, approximately, 167,800 + 133,000 = 300,800. The distance is 1,000 feet and the current is 40 amperes;

hence, $$\text{Drop } e = \frac{14.4 \times 1{,}000 \times 40}{300{,}800} = 1.9 \text{ volts.}$$

The total drop from m to k is, therefore, $4.3 + 1.9 = 6.2$ volts. This leaves $50 - 6.2 = 43.8$ volts drop for the outgoing and return feeders combined.

Feeder *1* with its return feeder will have to carry current for three cars, i. e., 60 amperes, and this current must be carried over $6{,}000 \times 2 = 12{,}000$ feet of wire. This part of the circuit will be of copper throughout and the same size of wire will be used both for the outgoing wire and the return. We have, then, using formula **1**,

$$\text{Circular mils (of outgoing and return feeders } \mathit{1}\text{)}$$
$$= \frac{10.8 \times 12{,}000 \times 60}{43.8} = 177{,}500.$$

A No. 000 feeder comes nearest this, although it may be a trifle small. It might perhaps be better to install a No. 0000 feeder, for the reason that four cars might easily become bunched on section *A*, and, besides, it is well to have some margin for future extensions.

Section B.—The drop from *b* to *a* will be 4.3 volts, that is, the same as from *h* to *k* in section *A*. The drop from *c* to *b* will be twice that from *m* to *h*, because the size of conductor and the current are the same, but the distance is twice as long. The drop from *c* to *b* will, therefore, be $2 \times 1.9 = 3.8$ volts. Car *d* will cause no drop in the trolley or main, because its current is taken directly from the feeder. The drop from *d* to *c* will be that due to 60 amperes through 2,000 feet of combined trolley and main;

hence, $$\text{Drop from } d \text{ to } c = \frac{14.4 \times 2{,}000 \times 60}{300{,}800} = 5.7 \text{ volts.}$$

Total drop from *y* to *a* $= 4.3 + 3.8 + 5.7 = 13.8$ volts, and the total allowable drop in the outgoing and return feeders is $50 - 13.8 = 36.2$ volts.

The current in feeder *2* will be that due to six cars, i. e., 120 amperes; the total length of outgoing and return feeder will be $4{,}000 \times 2 = 8{,}000$ feet;

hence, Circular mils (of outgoing and return feeder *2*)

$$= \frac{10.8 \times 8{,}000 \times 120}{36.2} = 286{,}400.$$

This is larger than No. 0000. Two No. 00 wires will give about 266,000 circular mils, but the best plan will probably be to use a 300,000-circular-mil stranded cable, as this will allow some margin on the large side and involve less line work. The return feeder will, of course, also have an equal cross-section.

21. Carrying Capacity of Feeders.—In making these calculations, no attention has so far been paid to the carrying capacity of the wires and cables that have been used. Of course, this point must be kept in mind, because if the lines are simply figured out on the basis of giving the allowable drop, it might happen that the current will be sufficient to overheat the wires. The accompanying table gives the approximate amount of current that the wires may be allowed to carry without causing the temperature to increase much over 25° F. above that of the surrounding air. These values are given by Mr. H. W. Fisher, of the Standard Underground Cable Company.

No. B. & S. Gauge.	Circular Mils.	Carrying Capacity, With a Rise in Temperature of 25° F., Approximately. Amperes.	No. B. & S. Gauge.	Circular Mils.	Carrying Capacity, With a Rise in Temperature of 25° F., Approximately. Amperes.
Stranded Cables.	500,000	509	2	66,370	124
	400,000	426	3	52,630	107
	350,000	388	4	41,740	91
	300,000	355	5	33,100	74
	250,000	319	6	26,250	63
0000	211,600	275	7	20,820	52
000	167,800	237	8	16,510	44
00	133,100	195	9	13,090	36
0	105,500	168	10	10,380	30
1	83,690	143			

In most cases, however, it will be found that the size of wire necessary to keep the drop within the specified limits will be considerably larger than that necessary to handle the current without overheating. Only in cases where the distances are short is there likelihood of the wire not being large enough. It is always well, however, to compare the sizes obtained and the current that the wires must carry with the values given in the table. If the wires should prove to be too small, the only thing to do is to use a wire that will carry the current safely or else run the risk of the wire overheating. If the larger wire is used, it will result in a somewhat smaller drop, but this will be an advantage, although the first cost of the wire will be a little higher.

22. Effects of Low Voltage.—In all the line and feeder calculations that have been made, the end in view has been to limit the drop to a certain amount. If the drop becomes excessive, either on account of the feeding system being too light or the load too heavy, it will produce a low voltage at the cars, and this in turn means low speed. It is a well-known fact that just as soon as the voltage on a system becomes low, troubles with the motors and car equipment begin to multiply. There are many cases on record where controller and brush-holder troubles have been very much decreased and where the roasting of field coils, controller blow-out coils, and the throwing of solder out of the commutator connections have been entirely stopped simply by raising the voltage on the line.

Let us suppose that a road having a certain number of cars is operated at, say, 550 volts and on a certain schedule. Suppose that, owing to an extension of the road, the addition of more cars, the deterioration of the track-return circuit, or any other reason, the voltage gradually comes down to 400. This will make a maximum decrease of about 20 per cent. in the running speed of the cars. If the time table is rearranged so that the motormen can run the cars on time with the same ease that they could with the higher voltage, the troubles with the rolling stock will not only not increase, but they will actually decrease, because the lower voltage is not as hard on the insulation and arc-breaking devices and the lower speed is not as hard on the car bodies and trucks.

If, on the other hand, no notice is taken of the gradual decrease in the average line voltage and the same time table is kept in force, the following will be the result: Since the maximum running speed of the cars has been cut down, the motorman must make up time wherever he can. Most of this will be made up at starting and getting the car under headway; part of it will also be made up on curves, crossings, and other places where, under ordinary conditions, slow running would be the rule. At starting, the controller is moved around rapidly and the car takes far more current than it should. This excessive current injures the controller, the commutator, and the brushes. The insulation on the fields becomes roasted and troubles of all kinds are liable to occur simply because the equipment has to be abused to make the car run on time.

As a practical instance of the result of low voltage, we may cite the following actual case that occurred where two abutting roads used each other's tracks for about $\frac{3}{4}$ mile. Their trolley wires were separated by a line breaker and each road had its own feeder system. On one side of the breaker the voltage was 425 volts; on the other side, 525 volts. As long as each road used only its own trolley wire the high-voltage road had no trouble to speak of. As soon as its cars began to run over the low-voltage road, controller and brush-holder breakdowns set in and continued until two extra feeders were run to the low-voltage side.

The above effects have been noted here simply to show that the question of proper voltage is an important one. It is true that there are many roads operating under an excessive drop, and this in itself is not so bad if the pressure at the station is increased so that the proper voltage at the cars is maintained. At the same time, a large drop means a large waste of power, and the question as to whether it will pay better to lose a considerable amount of power or buy more feed wire is something that must be determined by the relative cost of power and copper.

ELECTROLYSIS.

23. Introductory Remarks.—The subject of **electrolysis** is closely connected with the feeding system, especially the track-return part of it. By electrolysis in this connection is meant the eating away of the rails, underground pipes, or other buried metallic conductors by stray currents from the street-railway system. When electrolysis was first noticed, a great outcry was raised against the trolley roads by gas and water companies, telephone companies, and other corporations owning underground pipes or lead-covered cables. Many lawsuits were brought against electric-railway companies, and this led to an investigation of the subject. The result has been that electrolysis is not feared nearly as much as it once was, because means have been devised for avoiding it largely or for limiting it to sections where it can be watched or provision made to prevent it.

24. Elementary Principles.—In Fig. 7, *A* and *B* are two iron plates buried a short distance apart in damp earth. If the terminals of *A* and *B* are connected to a dynamo and a current is made to flow from *A* to *B* through the earth, we will find that plate *A* is eaten away or pitted, while plate *B* is not damaged. This is practically the same electrochemical effect that takes place in electroplating, where metal is taken from a plate or anode and deposited on the article to be plated. The point to notice is that wherever current flows *from* a metal conductor into the earth, the conductor is eaten away, but where current flows from the earth *into* the conductor, the latter is not damaged. The rate at which the metal will be eaten depends on the strength of the current. One ampere flowing steadily for 1 year will eat away about 20 pounds of iron or 75 pounds of lead, so that it is not hard to see that the damage due to this effect may be a very serious matter.

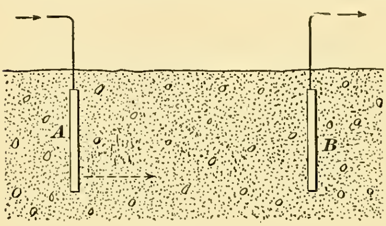


FIG. 7.

25. Electrolysis Due to Railway Currents.—Fig. 8 gives a simple illustration as to how electrolysis may occur in connection with an overhead-trolley system. *T T* is the trolley wire and *R R* the track. Under ordinary conditions, the current is supposed to return by way of the rail, as indicated by the arrows. If, however, there happens to be a pipe *L L* in the neighborhood of the track, and if this pipe offers a ready path for the current, part of the current will leave the rails, as at *I*, enter the pipe and flow out again at *O* to return to the power station. At *O*, where the current *leaves* the pipe, electrolytic action will be set up and in the course of time will eat holes in the pipe. At *I* the current leaves the rails; hence, the rails will be eaten away to some extent. If the trolley wire were connected to the negative pole of the dynamo instead of the positive, the current would flow out through the track, and whatever corrosion occurred on the pipes would take place at points

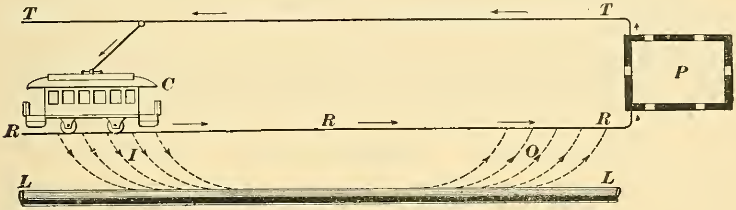


FIG. 8.

removed from the station and would be scattered over a wide area. On the other hand, with the positive pole connected to the trolley, whatever action takes place on the pipes is confined to districts near the power house. These areas are comparatively small, and measures can be taken to protect them. This is the principal reason why the positive pole of the dynamo should be connected to the trolley side of the line.

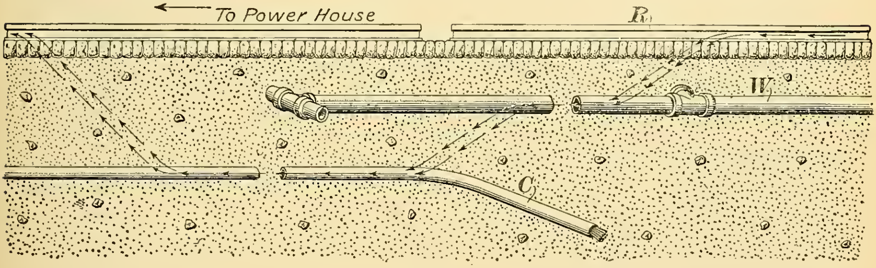


FIG. 9.

Figs. 9 and 10 show modifications of the simple case shown in Fig. 8. In Fig. 9, the current leaves the rail *R*, enters the pipe *W*, and flows through *W* until a better path presents itself in the shape of the lead-sheathed cable *C*. It flows along *C* until the track presents a better path, when it flows back to the rail again, as indicated by the arrows. Electrolytic action will occur where the current leaves the rail, the iron pipe, and the lead sheath of the cable. Fig. 10 shows a case where a cable and pipe run parallel to the iron rail *A B*, the arrows indicating the path of the stray current. Lead-covered underground cables are particularly liable to damage, because lead is eaten away much more rapidly than iron; moreover, the corrosion never takes place evenly, but in spots, so that the pipe or sheath becomes pitted and is soon destroyed. Wrought-iron pipes are more quickly eaten than cast iron; in fact, the harder grades of cast iron, such as chilled iron, seem to be very little affected.

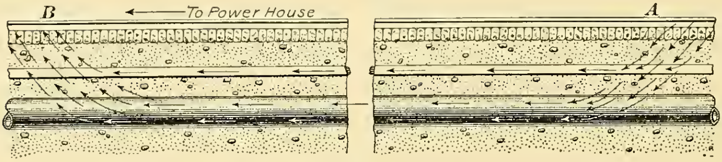


FIG. 10.

26. Influence of Resistance of Track Return. — It is easily seen, by referring to Fig. 8, that if the track return is in good condition, there will be little inducement for the current to leave the track and pass through the intervening earth to come back on the pipes. One of the most effective means, therefore, for preventing electrolysis is to see that the rails are thoroughly bonded. With the greater attention that is paid to good rail bonding on modern roads, there has been a corresponding reduction in the damage due to electrolysis.

27. Detection of Electrolysis. — As already stated, electrolysis occurs only when the current flows from the pipe or other conductor to the earth; in other words, the pipe or conductor must be at a higher potential than the surrounding earth. The dangerous points may, therefore, be located by going around to different parts of the system and taking readings of the voltage between the pipes or cables and the surrounding earth or neighboring pipes. If the pipe is positive to the ground, current will flow from the pipe to the ground; if, on the other hand, the pipe is negative and the earth positive, it shows that the current tends to flow towards the pipe and no harm is being done. After the dangerous localities have been located by means of these tests, return feeders can be run out to the danger points and attached to the pipes and track, so that the current will flow back on these feeders instead of leaving the pipes and causing damage.

28. Prevention of Electrolysis.—The ordinary precautions taken to prevent electrolysis on an overhead-trolley system have already been mentioned. The trouble is first localized near the station by connecting the positive pole of the dynamo to the line; next, the ground-return circuit is made as good as possible by thorough track bonding. Finally, tests are made to locate points where there is danger of electrolytic action and conductors run to these points to convey the current back to the station.

29. Systems Free From Electrolysis.—Systems using the double overhead-trolley and conduit systems, where the rails are not used as part of the return circuit, are, of course, exempt from trouble due to electrolysis. Roads operated by alternating current are also free from this trouble, but such roads are comparatively few in number.

30. Cars Operated on Three-Wire System.—Another scheme for preventing a great deal of the trouble due to electrolysis and at the same time using a higher line voltage is to operate the cars on the three-wire system, as shown in Fig. 11. *A* and *B* are the two tracks of a double-track road and *c*, *d* the two trolley wires. *G*, *G'* are two 500-volt generators connected in series and running the railway on the three-wire system. The track constitutes the neutral conductor, and it is evident that if the load on the two tracks is balanced, no current flows through the rails. The track return is called on to carry only the difference in the load, and as there are four rails to serve as a conductor, there is little tendency for the current to come back through pipes or other conductors. The use of this three-wire arrangement allows the power to be transmitted at 1,000 volts instead of 500, and therefore effects a saving in copper. The high pressure is, however, objectionable, especially in thickly populated districts, but it seems as if the system would be well adapted for cross-country and suburban lines. The saving in copper is not as great as that effected in changing a two-wire lighting system to a three-wire system, because in the simple 500-volt trolley system the track is already utilized, whereas in the three-wire method of operation it is used very little. The saving in copper will, however, be from 20 to 40 per cent., depending on the quality of the track return.

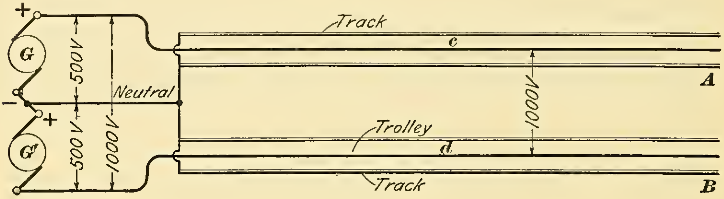


FIG. 11.

Fig. 12 shows the three-wire system used on a single-track road. The trolley wire is here cut into sections, the length of which depends on the traffic. These sections are connected alternately to the two sides of the system and the track forms the neutral conductor. By choosing the length of the sections properly, the load on the two sides of the system may be balanced closely enough for all practical purposes.

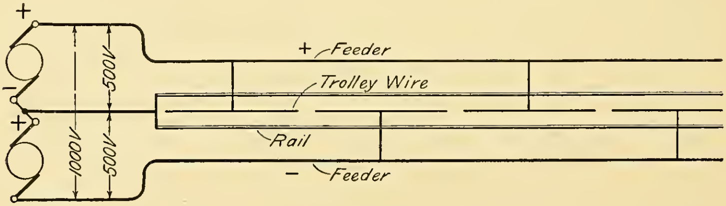


FIG. 12.

LINE TESTS.

31. With the ordinary overhead-trolley system it is not, as a rule, necessary to make many tests of the overhead conductors. One side of these systems is always grounded, so that if a ground occurs at any point, due to poor insulation or any other cause, a short circuit results and the fault is either burned out or some indication is given, so that there is little difficulty in locating it. The insulation of the system may be measured by the voltmeter method.

There are, however, two special tests that are sometimes used in connection with electric railways that we will describe briefly. These are tests for defective rail bonds and track resistance.

32. **Tests for Defective Rail Bonds.**—Rail bonds are liable to work loose in time and develop bad contacts, and it is necessary to have some convenient means for detecting bad joints. Fig. 13 shows one device that may be used for this purpose. It consists of a flat wooden straightedge about 6 feet long provided with three spring contacts *a*, *b*, *c*. When this straightedge is laid on the track, contacts *a*, *b* span the joint and *b*, *c* a fixed length of rail. *V* is a millivoltmeter (a voltmeter reading to thousandths of a volt) connected to the contacts *a*, *b*, and *c*, as indicated. *R* and R_1 are resistance coils of about 10 ohms each, and are used to prevent the connecting-in of the voltmeter from appreciably affecting the current in the rail. Small switches *S* and *S′* are provided, so that the voltmeter may be connected either between *a* and *b* or between *b* and *c*. The voltmeter should have the zero point at the center of the scale, so that the readings will be on opposite sides for currents through the two circuits. Now, when current is flowing through

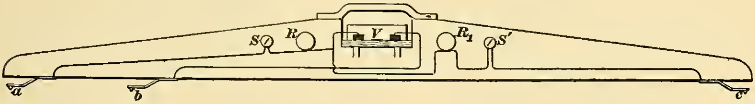


FIG. 13.

the rail and joint, the voltmeter reading between *b* and *c* will be proportional to the resistance of the section of rail between *b* and *c*, and when the voltmeter is switched to *a* and *b*, its reading will be proportional to the resistance of the joint. In this way, the resistance of any joint as compared with a fixed length *b c* of rail can be determined, and since the resistance that a good bond should have is known for the particular styles of bond in use, it is easy to determine just about what ratio the two voltmeter readings should bear to each other for a joint that is in good condition. If the reading across the joint is abnormally high as compared with that across the rail, the bond should be repaired.

33. Fig. 14 shows another method of detecting bad joints, which is similar in principle to the one just described. In this case a telephone is used for an indicator instead of a millivoltmeter. The telephone is a good instrument for this purpose, as it is very sensitive and is easily carried about. The operator on the left is provided with two poles having pointed metal terminals. Flexible wires lead from these terminals to the box carried by the second operator, who also carries a similar rod connected to the box, as shown. This box contains an interrupter that interrupts the current flowing through the head telephone worn by the

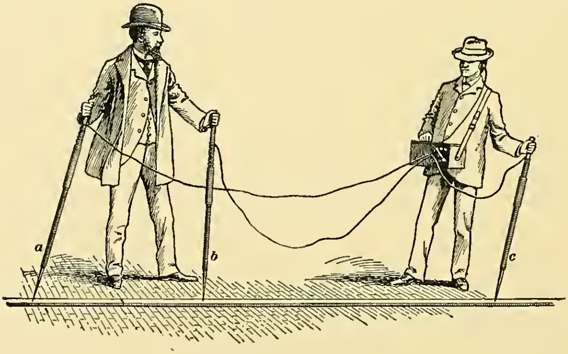


Fig. 14.

operator, and thus causes the telephone to make a noise. Poles *a* and *b* are placed about 3 feet apart, so as to span the joint and fish-plate. Pole *c* is placed about 4 or 5 feet from *b*. By means of the switch the telephone is thrown first across one span and then across the other, the pole *c* being shifted until the sounds obtained for the two different positions are nearly the same in loudness. The switch on the box is then thrown to the middle position and the position of *c* more accurately adjusted, until little or no sound is heard in the telephone. When this condition of affairs is reached, the resistance of the length of rail between *b* and *c* is equal to the resistance of the joint between *a* and *b*. Since the weight of rail per yard is known, the resistance of the joint may be calculated from the known length *b c*. Usually, however, this will not be necessary, because the test is used principally for locating bad joints, and comparative results are what are looked for more than absolute measurements.

It will be noticed that the above test makes use of the current flowing in the rail, but is independent of the variations in this current, because the same current flows through both rail and joint. The use of the telephone instead of a voltmeter allows the tests to be carried out conveniently and rapidly. Fig. 15 shows the connections of this testing outfit. *A* is the vibrator, *B* the telephone, and *C* the three-point switch. *R* and *R'* are two similar resistances. When the resistance between *a* and *b* is equal to that between *b* and *c*, it is evident that no current will flow through the telephone when *C* is on the middle point, because points *x* and *b* will be at the same potential.

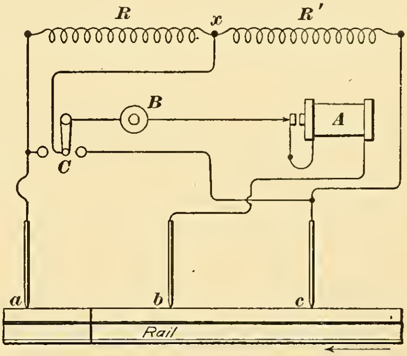


FIG. 15.

34. Testing Resistance of Track-Return Circuit.—After a road has been in operation some time, it is often found that the drop on certain sections is larger than it should be, and it becomes necessary to remedy matters. The question naturally arises as to whether the track return is at fault or whether more copper is required in the overhead feeders. In order to find this out, it is necessary to know the comparative resistances of the two. If the track resistance is high compared with that of the overhead line, the track return needs attention, and *vice versa.*

Fig. 16 shows one method of measuring the resistance of a railway circuit. *F F* is the feeder running out to the section under consideration and *R R* the rail return. A time is selected at night, when traffic can be kept off the section for a short time, and a water rheostat *W* is connected in series with the feeder *F* and the regular feeder ammeter *A*. The feeding-in point *x* is connected to the track by any convenient means, as shown at *x y*, and a steady current is sent through the circuit *G* + –*W*–*A*–*c*–*F*–*F*–*x*–*y*–*R*–*G*—. The drop through the entire feeder and rail circuit is measured by a voltmeter *V* connected to *c* and *b*. From the readings of *A* and *V*, the total resistance of the feeder and rail circuit is at once determined. The resistance of the feeder *F F* can be calculated from its known length and cross-section, and its resistance subtracted from the total resistance of the circuit will give the resistance of the track return.

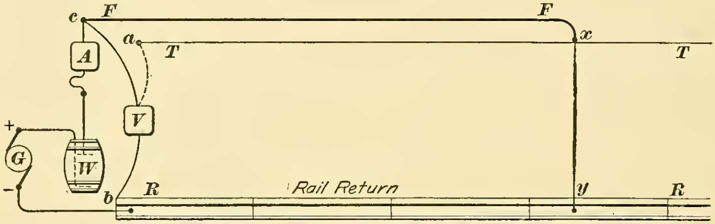


FIG. 16.

The above method of finding the resistance of the track return assumes that there are no bad joints or unusually poor conductivity in any part of the feeder *F F*, but such is not always the case. If the trolley wire runs back to the power house or if there is another feeder nearby that can be used as a pressure wire, the drops in the feeder and track may be measured separately and an accurate idea gained as to just how the drop is distributed. For example, if the upper voltmeter terminal is connected to the end *a* of the trolley wire instead of to *c*, the reading obtained will be the drop through the track alone, because the voltmeter takes such a small current that there will be practically no drop through Tx. If one terminal of the voltmeter is connected to *c* and the other to *a*, the reading obtained will be the drop in the feeder FF. This method is the one to be preferred, because it at once gives an accurate comparison between the loss in the overhead work and the loss in the track and shows what part of the system requires attention in order to bring about better working conditions.

AUXILIARY EQUIPMENT.

35. We have already considered that part of an electric railway system that pertains directly to the supply of current for the cars. The rolling stock and car equipment remain to be considered, but before going on to this part of the subject, it may be well to pay some attention to what might be called the auxiliary departments of a road. Under this head may be included car houses or car barns, repair shops, etc. These, while not, perhaps, directly connected with the running of the cars, are at the same time an essential part of the road. Their equipment varies greatly on different roads, so that the descriptions can only be very general in character.

THE CAR HOUSE.

36. The **car house** or **car barn** is a building used for storing cars that are not in use; that is to say, either for storing the regular schedule cars during the hours when they are not in use or for storing closed cars in hot weather or open cars in cold weather. The ideal arrangement would be to have the repair shops, the car house, the power station, and the general offices all centralized, as it would effect a great saving in time and labor; but, unfortunately, in most cases this cannot be done, especially on large systems. The nature and extent of the traffic dictates the location of the power stations, and the cost of land that of the repair shop and car houses. Of course, in many cases, a large system is the result of the consolidation of several smaller ones, and this always introduces objectionable conditions that cannot be overcome. On the small roads, it is not so difficult to centralize the buildings. On the large roads, it is the custom to have one large, well-appointed repair shop as centrally located as possible in regard to the several depots from which the cars are sent out on their runs. These depots generally constitute a sort of combination car house and auxiliary repair shop, where light repairs are done to avoid sending the cars to the main shop. Such a combination depot should, from the storage point of view, be as nearly fireproof as possible and should have all the facilities for extinguishing a fire.

Where practicable, the tracks should be far enough apart to admit of easy passage between the cars, and the more uniformly the daylight is diffused throughout the building, the better. In some car houses the storage room is all on one floor; this may be the first or second floor, according as the cars to be stored are out of season or are just temporarily out of use. In other storage houses, two or more floors are used, in which case an elevator must be used for handling the cars on the upper floors.

Where the cars must be transmitted to and from an upper story by means of an elevator, it is almost always the case that the stripped or out-of-season cars are stored there. As there is no possible chance of saving the cars in time of fire, there is no objection to setting them on horses or barrels; but where the storage tracks are on a level with a street track, the cars should be set upon temporary trucks, so that at an alarm of fire they can be run out. For ordinary over-night storage of cars, the practice of having all cars depend on the use of a transfer table to take them to a track that leads to the street is a bad one, on account of the great fire risk. Where practicable, every storage track should lead to the street at one end or the other of the car house. In some houses it is the practice to grade the rails down to the street, so that in case of fire it is only necessary to let off the brakes and the cars will run out. That part of the car house that is to be devoted to light repair work should have every facility for inspection and repair. There should also be a stretch of about 40 feet of double track, where the cars come into the house, provided with a cement or other waterproof floor, draining to the sewer or to a cesspool. This is to be used for washing the cars as fast as they come in for the night.

37. For inspection of trucks and motors there should be **pits** about 4 feet 8 inches deep directly under the tracks, no pit to be shorter than any car that may be placed over it. As to the total amount of pit room required per car, it is a very hard matter to fix between narrow limits, as it depends a great deal on how much trouble the equipments give. A safe value, however, based on long experience with almost all conditions of working with several types of motors and trucks, is 1 linear foot of pit room for each car that runs into the depot; that is to say, a depot handling 100 cars could get along with 100 feet of pit room without a great deal of shifting. The arrangement of this pit room will depend considerably on the arrangement of the tracks in the house. An ideal arrangement would be to have four pits 25 feet long each, or three pits 33 feet long each, according to the length of the cars to be handled. The pits should have cement bottoms and be properly drained. The space between the tracks on the floor level should be boarded, but the underneath space between the pits should be left open.

A couple of shelves and a row of small bins to hold a few of the most commonly used sizes of bolts, nuts, and washers save time and should be placed in each pit. Each pit must have a *pit jack*, which is a common pump jack with its rack made longer and terminating at the top in a kind of cradle to hold an armature without bruising it. The jack is provided with a pivoted base mounted on a four-wheel truck. The class of work that it is profitable to do at the outside depots is the changing of motor armatures, field coils, brush holders, bearing wheels, and controllers, and the supplying of missing bolts, nuts, washers, and other small parts, together with the general repair and adjustment of brake rigging. A hand forge and a blacksmith that can make himself useful in other lines of work are usually necessary in any depot running out more than 30 cars. A small drill press and lathe for boring bearings and for drawfiling or turning down armature bearings to standard size, or putting on heads or bands, will soon pay for themselves in a depot shop if operated by a man that can make himself otherwise useful.

38. Wiring of Car House.—The wiring of the car house is a simple matter, but its plan depends on the track layout of the house. Every track should have a trolley wire over it. The house trolley wiring, as a whole, should be separated from the main line outside by means of a line circuit-breaker; it must then be connected to the street wires by means of a jumper that passes through a switch placed outside of the building, so that in case of fire the whole house wiring can be disconnected. The wires in the house are supported on barn hangers made for this class of work (see Fig. 17). The hanger is fastened to the house beam by means of lugs *b*, *b*, the trolley wire being fastened to ear *c*. In iron barns, the hanger must be screwed to wooden blocks supported from the iron girders. In some

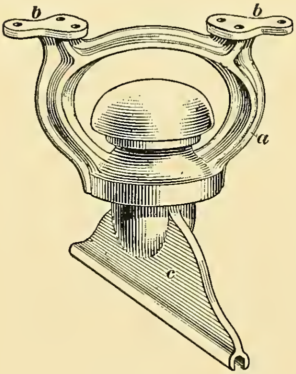


FIG. 17.

barns, the trolley wire is run in an inverted wooden trough placed over it, and the hangers are screwed to the bottom of this trough. In such a case, the trough generally catches the wheel if for any reason it leaves the wire; it also serves as an insulated support for the wheel at night and obviates the necessity of tying down the pole where such a rule is in force. In a metal barn, it makes it impossible for the trolley pole to come in contact with the metal structure and the live wire at the same time if the pole should fly off the wire. Sometimes at short curves under very low structures it is the practice to do away with the trolley wire altogether and replace it with an inverted brass or copper trough, in which the trolley wheel rolls along on its flanges.

39. When the car house is situated near the street line, the several tracks running into it should not start from the main line, but a siding *s*, Fig. 18, should be laid out so that through cars need not go over so many switches. Those from the left pass over the switch *a* only, those from the right over *b* only, saving some amount of wear and tear on car wheels and greatly prolonging the life of the switches.

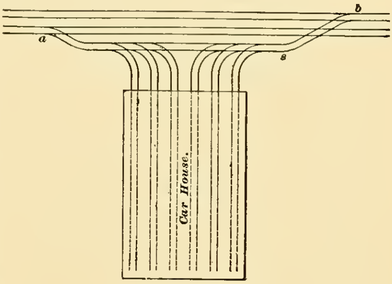


FIG. 18.

THE REPAIR SHOP.

40. The repair shop is the place where all heavy repairs and alterations are made. A well-appointed repair shop should include a *pit room*, *machine shop*, *carpenter shop*, *mill*, *blacksmith shop*, *paint shop*, *winding room*, *commutator room*, *controller room*, and a *wheel-grinding annex*. In the pit room, all truck and motor repairs are made. In the machine shop, all general machine work is done, such as fitting bearings, turning down commutators on the shaft, recutting bolts, etc. In the winding room, fields, armatures, armature coils, etc. are wound, insulated, and baked. In the commutator room, the parts of the commutator are assembled and the finished article tested. In the controller room, controllers, switches, resistances, etc. are repaired. In the mill, the repair parts for car bodies are made. The best place for the machine shop is in the rear end of the pit room, and the worst place for the forges is next to the paint shop. The armature room should not be exposed to the dust from an emery wheel, and it is equally important that the commutator room be well protected. The shop building should be a substantial fireproof structure and every effort should be made to have good light throughout.

41. The Pit Room and Machine Shop.—The number and length of the pits depend on the nature of the work to be done and the number of cars to be handled. If no armature, field, wheel changing, etc. is done at outside depots and must be done at the main shop, 1 linear foot of pit room per car is about right. The pit rails should be laid on stringers supported by brick piers, and the space underneath between pits should be left open, so that a man can go from one pit to another without going up on the floor. There should be means provided for raising the car bodies off the trucks quickly and with as little labor as possible. A cheap way to do this is to hang over each pit three rails, along which chain falls are free to move from one end of the pit to the other. The center overhead rail is over the center of the pit, and its hoist is used in the truck and motor work after the car body is up. On each of the two outside rails are two chain hoists, and the hoist rails are just far enough outside of the track rails to have the hoists clear the car under all conditions. The system is made more efficient if the hoist rails of neighboring pits are connected at the ends, so that a set of falls can be run over from one pit to another. Only one set of falls is required in each pit, for if more are needed, the car bodies can be set on barrels or horses to free the falls. To avoid the use of extra long hoist chains, the falls are suspended from the carriages by long double eyebars. In conjunction with the hoists are used two wooden beams with an eyebolt in both ends to take the **S** hook that engages the hook on the chain fall; 2,000-pound hoists are heavy enough for single-truck cars, but in case any extra heavy lifting may arise, it is well to provide one pit with 4,000-pound hoists. With such an outfit, two men can raise a single-truck car in about 5 minutes after the body bolts are out and the motors and brake rods are disconnected. The chain falls should be oiled once a month. It is becoming common practice to provide car shops with an air compressor and reservoir, the air to be used in blowing the dust out of motors, controllers, etc.; in such a case, the compressor, or air pump, is driven by a motor. The air pump stores the air in a main reservoir that is piped to auxiliary reservoirs situated at the points where the air is to be used. Air has proved to be the best thing for cleaning purposes, and in the several instances where it has been used as a means of operating lifts to raise cars and to handle heavy work around the lathe and boring machines, it has scored an equal success.

42. The Machine Shop.—In laying out a machine shop, two important points must be kept in mind: the machines must be so disposed as to admit of having a good light thrown on the work and at the same time must take up as little floor space as possible. The number and kind of machines to be installed depend on the class of work to be done. There should be enough machines so that the work may not be held back for want of them, but at the same time there should be no more of the same or similar kinds than can be kept busy. The repair shop must frequently work overtime, and on this account it is advisable to have it run from a small independent motor, so that in case one or two machines have to be used on overtime, it will not be necessary to run the whole repair shop.

The machines necessary to equip a machine shop are about as follows: One lathe to take an axle with the wheels on it; one smaller one to take armatures and bearings; one speed lathe; one metal saw; one large and one small drill press; one planer and shaper; one bolt-cutting machine, with right- and left-hand dies; one milling machine; one wheel press; one axle straightener; emery wheels; one grindstone; one power hack saw; one ratchet drill; one punch press; and one power hammer, usually in the blacksmith shop. On a large road, the regular shop work, together with that of power houses, line, and track, will keep the above equipment busy most of the time. On a small road, some of the above might be omitted. The machine-shop practice should be managed so as to do the best and safest work with the tools and stock in hand. The idea of interchangeability of parts should be pushed as far as it will go, even if some other things must be sacrificed.

43. The Winding Room.—As good a place as any for a winding room is in a gallery built around the wall above the machine shop, but a great many object to this plan on the ground that all cores to be wound and wires for winding must be elevated to the gallery. This is true; and where there is plenty of room on the ground floor, it is best to do the winding there; but where space is limited, the above location is a good one, for in case the winding-room motor gives out, there is the shafting below to fall back on. If ground space is available, it can be put next to the machine shop, being separated from it by a fireproof, self-closing door. The machine-shop shafting is extended through and made ready to couple on in case of a breakdown. The size of the armature room required for a given number of cars depends, of course, on many local conditions, among which can be mentioned the type and age of the equipment in use; the condition of the track and line work, and therefore, to a degree, the constancy and value of the normal voltage maintained on the line; the number of different kinds of motors in use and their adaptability to the class of work they are called on to do; the competency of the motormen who handle the cars; and a number of other causes.

For a road operating 100 cars or over, from 6 to 8 square feet of floor space per car should be sufficient for the winding room. For a small road, the space required per car would be much larger. Every winding room that does all its own work, i. e., carries out all the processes of winding and does not buy its armature coils ready-made, should be equipped with about the following: One machine for putting bands on armatures; one field-winding machine; one armature-coil winding machine with a coil former for each type of armature; one gasoline stove, brick-enclosed, with the tank well removed and enclosed (gas is better and safer when it can be had), for heating soldering irons; a device for pulling off commutators (the pinions should be removed before the armatures are sent in); racks for holding rolls of insulation; stands for holding armatures in course of winding; one machine for cutting insulation; one machine for pressing coil papers; one coil press for each kind of coil; ample facilities for dipping the coils in varnish or some other compound; racks for holding completed armatures; an oven or its equivalent for baking armatures (it can be either steam heated or heated with street-car heaters). If the armature coils are dipped in an air-drying compound, no oven is needed, because the armatures themselves and the fields and other coils can be baked by sending a current through them; but if the armature coils are to be dipped in varnish—a much better practice—an oven must be provided, and it might just as well be large enough to bake everything.

The winding room should be provided with substantial patterns of every standard piece of insulation used in the place; one set of these should be hung in a convenient place; a duplicate set should be kept under lock and key, preferably in a fireproof place.

44. The Commutator Room.—The commutator room should be in charge of a good mechanic, and should have in it a lathe, a drill press, a milling machine, and a gas or gasoline oven for baking the commutators. It should be provided with a full line of gauges for the several kinds of mica bodies used and taper plug gauges for the shaft hole bored in the shell. In modern practice, commutators all fit on a tapered seat on the armature shaft, and it is essential that the commutator should go on just so far and no farther. There should be provided a device for tightening up the nuts without twisting the commutator bars out of line. There must be an adequate supply of assembling rings and the proper wrenches for adjusting them; and no emery wheel should be allowed in the commutator room. The most natural and convenient location for the room is next the winding room. The commutator room should be enclosed, but should have the best possible light and ventilation.

45. The Controller Room.—There is no particular condition to be fulfilled in selecting a site for the controller room. A location just off the machine shop, where it will be convenient to the machines, is as good a place as any.

46. The Mill and Carpenter Shop.—The mill is the room in which the wood-working machines are placed. The carpenter shop is the room where the cars are run in for general body repairs. There is no reason why they should not both be within the same enclosure—the mill at one end and the carpenter shop at the other. The best place for them is between the machine shop, pit room, and paint shop, a line of single or double track running through, so that a car can come in at one end of the building and go out at the other. In the mill there should be a planer, a boring machine, a lathe, a band saw, a circular saw, and a grindstone. The mill should be run from its own motor or from the one in the blacksmith shop. In either case, the motor should be caged off to save it from the dust and should be cared for more than the others.

47. The Paint Shop.—The paint shop should be at the extreme rear of the main shop and should have free access to the street; it should be provided with as many doors on the street side as there are tracks, so that in case of fire the cars can be run out without any shifting or transferring. The paint shop should receive only cars that have been repaired and are ready to run on the road except for the painting. This being the case, each track in the shop should have a trolley wire over it, the whole system of trolley wires being kept cut out by means of a switch except when they are to be used. Of course, in cases where open cars are painted in the winter and closed cars in the summer, and there is but a single set of trucks for the two sets of car bodies, it will be necessary to run the bodies in on temporary trucks. Under no circumstances should the car bodies be set on horses or barrels in the paint shop. The risk of fire is too great; they should always be on temporary trucks, and where possible, at the head of each line of cars should be a car fully equipped, so that in case of fire they can be all coupled together and towed out of danger. Another good plan is to have the tracks down grade out of the house, so that when the brakes are released or the chocks removed from the wheels, the cars will run out by gravity. On account of the great fire risk incidental to the storage of so many inflammable materials, oils, varnishes, etc., there should be an absolutely fireproof wall between the paint room and the rest of the shop, communication between the two shops being only through self-closing fireproof doors. As a prime precaution against fire, the building should be of brick, with an iron roof and a cement floor. The floor should be graded to gratings that lead to the sewer or to a cesspool and the roof should be designed to give the best possible light and ventilation. All inflammable materials should be kept in a small, absolutely fireproof room that will admit barrels, etc. without trucking them the entire length of the paint shop. The question of fire risk in a paint shop is a serious one, for the reason that the shop is generally full of cars that will burn quickly if once started.

48. The Blacksmith Shop.—The blacksmith shop must be located where the coal dust and gases from the forges cannot reach the paint shop. If there is a cellar with a good light and a dirt floor, it makes a good place for this shop. In the blacksmith shop should be at least two forges, anvils, and a blower. One forge should be provided with an ordinary bellows all ready to be connected on, in case anything should happen to the blower or to the motor from which it is run. Besides the usual complement of forge tools, there should be a machine hammer, shears, and a drill press.

49. The Grinding Room.—If the breaks on a trolley car are applied too hard or if for any other reason the car skids along the track, flat spots, or **flats,** as they are called, are found on the tread of the wheel. These make the wheels pound on the rails, and unless they are removed by grinding or a new wheel put on, the trouble is liable to go from bad to worse. Practically all car wheels are of chilled cast iron. In the molding the tread of the wheel is chilled so that the iron is very hard for a depth of $\frac{3}{8}$ or $\frac{1}{2}$ inch. If the wheel is ground down so that the chilled portion is ground through, there is no use in doing anything further with it, as the iron under the chilled part is too soft to last any length of time. Flats are removed by means of a grinder, which is a device for holding a revolving emery wheel against the tread of the wheel to be ground. The wheels may be ground either in place on the car or separate from the car. The car-wheel grinder can, as a rule, be used to greater advantage out at one of the depots, if the wheels are to be ground on the car; this is undoubtedly the best practice, but it is not always followed. Where the wheels are taken out to be ground, there must be extra means provided for driving the axle, whereas, if ground on the car, one of the car motors can do the work. In either case, the car wheels should make from 20 to 40 revolutions per minute, and the speed of the rim of the emery wheels should be about 5,000 feet per minute. There are several types of car-wheel grinders on the market, and they are all good enough to soon pay for themselves. In general, a grinder must have two hardened centers supported in a substantial frame on both sides of the track; these centers must be movable up and down, so as to meet the requirements of different sized wheels. If the wheel is so small that the emery will not reach it when the axle is swung on the straight centers, drop centers can be used, but this is seldom necessary. The emery wheels must admit of being fed to and from the wheel and also across the wheel. The bearings must be protected from the flying dust or they will soon be cut up.

If a car is brought in when the flat begins to sound, it can be ground in from 20 to 50 minutes. Even if it takes 2 hours to grind a pair of wheels, it is profitable to do so provided the result of the grinding is not to bring the tread down below the chill. This condition can be ascertained in the course of grinding by knocking the tread of the wheel with a hammer; if the chill is gone, the hammer will easily make a dent. This should also be tried before the axle has been centered. As a rule, one wheel on an axle will be found to be a good deal flatter than its mate; this is due to the fact that on most roads sand is applied to the rail by means of a sand box on each car, and it is always the wheel on the sand-box side that has the deepest flat, because in most cases the flat is due to locking the wheels before applying the sand and then sliding the locked wheels into the sand. Experience has proved that trouble from flat wheels can be to a great extent eliminated by sanding either one or both rails from a sand car; this applies the sand continuously and lessens the chances of the car wheels beginning to slide. Notwithstanding that one wheel may need more grinding than the other, they must both be ground down to within $\frac{1}{16}$ inch of the same diameter. When one wheel is larger than its mate, there will be more or less slipping, and this develops more flats. To grind the small wheels on double-truck cars, a device must be rigged up to turn them, as they have no motor of their own to do it. There has been a great deal of discussion as to whether it pays to grind car wheels or not, and it is safe to say that it pays to grind some wheels, while others it does not. On the whole, a car-wheel grinder will soon pay for itself in many ways if the wheels are brought to it when they should be.

ELECTRIC RAILWAYS.

(PART 5.)

MOTOR CARS AND THEIR EQUIPMENT.

1. General Description of Equipment.—As a rule, the term **rolling stock** as applied to an electric railway is taken to mean the car bodies and trucks, including sweepers and snow plows. Under this head we will also consider the motors, controllers, and other devices necessary for the operation of the cars.

Besides the car body and truck, with its brake equipment, an ordinary trolley car is provided with *motors* (usually two or four per car), two *controllers*, two *canopy* or *hood switches*, one *lightning arrester*, one *fuse block*, one *trolley base*, and one *pole*, with its *harp* and *trolley wheel*. These various devices will be described in detail later. It is now becoming common practice to equip cars with *circuit-breakers* instead of canopy switches and fuse blocks. The equipment also includes one or more *lighting circuits*, and in many cases a *heating circuit* also.

CAR BODIES.

2. The **car body** constitutes the main part of the car and is mounted either on a single truck or on two trucks, depending on its length. Car bodies are made in a large variety of styles. Some are open for summer use, others are closed, and others are a combination of the two. They are made in lengths from 18 or 20 feet up to 40 or 50 feet. The larger cars usually have the seats arranged crosswise, like an ordinary railway coach.

3. Selection of Car Body.—The selection of the cars for any given road is a matter that requires careful attention. No fixed rules can be laid down to govern the selection of the car body in all cases, because conditions vary. A body that is adapted to one place and condition of service might fail entirely to meet the requirements elsewhere. In some places, open cars can be used the year round, while in other sections there are only a few days in the year when closed cars are uncomfortable. The average conditions call for both open and closed cars, and much attention has of late been paid to the question of devising a car that can be made an open car in warm weather and a closed one in cold weather. The result of much study, experiment, and expense has been the so-called *convertible* or *combination* car, a type which all car manufacturers now make. The nearest approach to a solution of the problem of producing a combination car that is as good in hot as in cold weather is found in the car that is partly open and partly closed. This car has the advantage that it is not only adapted to hot and cold weather, but to rainy weather as well. It has the disadvantage that in no kind of weather does it, as a rule, carry a full load, except during the rush hours, so the power house must carry just so much dead weight over the road. The convertible cars, with removable or sliding panels, can be hardly said to have had a fair trial yet, but there is no doubt that it would be a great saving for a road to have a set of cars that could be run with perfect comfort to the passengers all the year around. It means that little more than half the number of cars need be bought and maintained; also, that every car on the road would at all times be equipped and ready to run.

Cars are constructed according to many different designs, depending on the particular uses to which they are to be put. The single-truck four-wheel car is fast giving way to double-truck eight-wheelers, because a single truck, on account of the limited wheel base, cannot well accommodate a car body over 20 or 22 feet long, and it has been found that in most cases it pays better to run long cars at long but certain intervals than to run short cars at shorter intervals. The most economical practice of all, from the energy point of view, is to run **trailers**. A trailer is a car similar to a motor car, but it is lighter and is not equipped for running itself. On account of the trailer being so light, the ratio of live weight to total weight carried is very much increased, and also the trailers can be left off when they are not needed. But unfortunately the use of trailers increases the number of accidents and consequent damage suits, and these more than offset the value of the power saved.

The point must often be decided as to whether single-truck or double-truck cars should be purchased for a road. It can be safely said that if there is the least doubt as to which to buy, give the preference to the double-truck car. There is nothing so attractive as a well-built and well-appointed double-truck car. This type of car is easier on the car body, easier on the line work, easier on the track, and last, but not least, it is easier on the passengers. Actual statistics have shown that the introduction of the double-truck car will create travel. Being higher from the rail and longer than the single-truck car, it takes longer to load and unload passengers, and for this reason is not adapted to local runs, where the travel is heavy and the stops frequent. This, of course, does not apply to open cars, where ingress and egress are just as free as on a single-truck car.

TRUCKS.

4. The main requirements of a good truck are that it be easy riding, durable, have few parts, wearing parts easily replaced, and wheels easily changed. The trucks must be entirely self-contained; that is, the one framework must include the wheels and axles, the brakes, motors, and driving gear. This in reality constitutes the car, for the car body above is merely a framework to hold and shelter passengers, having none of the vital parts necessary to operation. The fact must not be overlooked, however, that the car body has to stand severe strains on account of the rapid acceleration at starting and an equally heavy strain when the brakes are suddenly applied in stopping; so that this portion of the car must be carefully designed or it will not last long.

5. Classes of Trucks.—Trucks are of two kinds: **single trucks** and **double trucks.** Double trucks are of two kinds: *ordinary double trucks* and *maximum-traction trucks.* A single truck has four wheels, takes a single motor on each axle, and there is one truck to a car. An ordinary double truck has four wheels, all the same size, can take a motor on each axle, and there are two trucks to a car. A maximum-traction truck has two large wheels and two small ones, the idea being to throw most of the weight on the large wheels, to whose axle the motor is hung and geared. The weight on the small wheels is regulated by means of a compression bolt and spring, just enough compression being put on to keep the small wheels on the rail when rounding curves. As a rule, the large wheels take about 70 per cent. and the small ones 30 per cent. of the total weight. Experiment has proved that for a given weight of car, the maximum-traction trucks do not require as large an expenditure of energy as a single truck with a 7-foot wheel base. The single truck, being more rigid, binds more in curves and does not equalize as readily as the maximum-traction truck, with its shorter wheel base. The ordinary double truck equipped with a single motor has the disadvantage that the driving power is all on one axle, while the weight is divided between two. The result is a tendency for the driving wheels to spin when called on to do heavy duty, because the traction, that is, the friction between the wheel and the rail, is not great enough. By putting a motor on each axle, making four motors to the car, conditions are much improved.

Neither maximum-traction nor ordinary double trucks are as well adapted for use on an icy rail as the single truck. A single truck will go up an icy grade that neither of the other trucks can ascend.

The car body is rigidly bolted to a single truck by body bolts passing through the car sills and the top rail of the truck's side frame. Double trucks are attached to the car body by means of center bearings and pins, around which the truck turns as a center. Part of the weight is sustained and the car body kept balanced by the **rub plates**, which are circular pieces of brass that engage mates attached to the car body. These rub plates should be kept well greased. Cars mounted on double trucks sit higher from the rail than single-truck cars, because the body of the car has to clear the wheels and motors. In open cars the truck wheels have to clear the side steps, so that in some cases two steps must be used.

6. Types of Trucks.—Fig. 1 is a type of single truck; Fig. 2, an ordinary double truck; Fig. 3, a maximum-traction truck. In Fig. 1 the motors are supported by the suspension bars *b*, *b*, and these bars are in turn supported by the springs *s*, *s* resting on the side frame of the truck. The method of mounting the motors will be explained more in detail when the subject of motors is taken up. Since it is advisable to support the motor on springs, it is, of course, equally necessary to provide a flexible support for the truck frame and car body. For short cars, springs placed close to the wheels would be sufficient, although such a construction would have little merit. The reason for providing a longer spring base is to prevent oscillation, which is unpleasant for the passengers and hard on the car body. The oscillation when excessive diminishes the traction on the rising end of the car and causes the wheels to slip. For these reasons, the spring base is extended by adding extra springs at S_1, S_1. The car wheels generally used with such trucks are 30 or 33 inches in diameter, and the trend of present practice is towards the larger size, because it is heavier, raises the

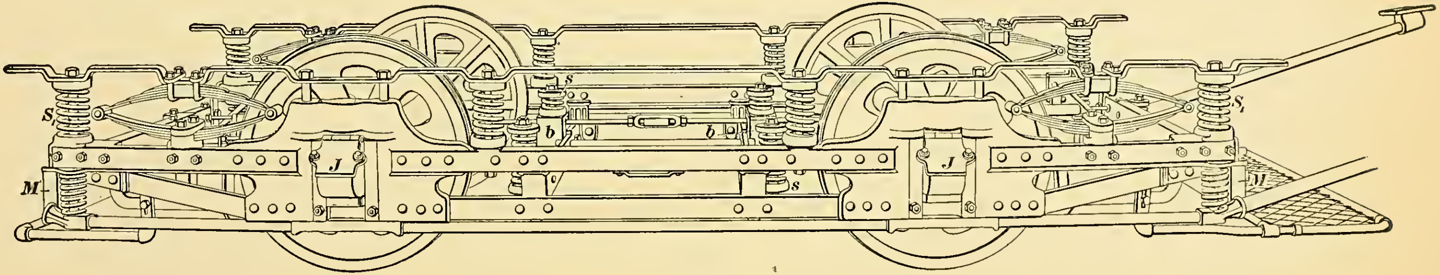


FIG. 1.

bottoms of the motors farther from the paving, allows higher speed, and gives less trouble from breaks and flats. The axle bearings are outside of the wheels, to give stability to the car body, the journal-boxes *J* being free to move vertically through a short distance controlled by a heavy coil spring or rubber washer. Rubber does not amount to much as a cushion after it is old, because it becomes very hard.

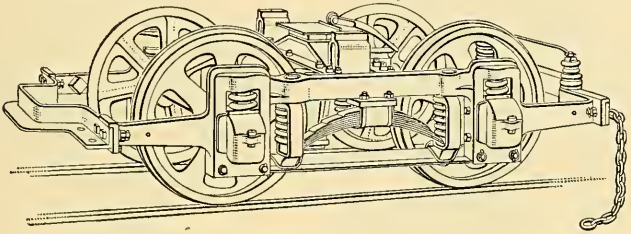


FIG. 2.

Fig. 4 shows a larger view of the bearings used on a single-truck car; *a* is the journal and *b* the bearing brass, which is on the upper half only, because the thrust is all in one direction. This brass presses against the box casting *c*, which in turn bears up against the spiral springs *s*, that are held in a socket in the frame *f*, as indicated in Fig. 4. By removing the piece *d*, the frame can be lifted clear of the axles. The journal is lubricated by means of waste *g* in the

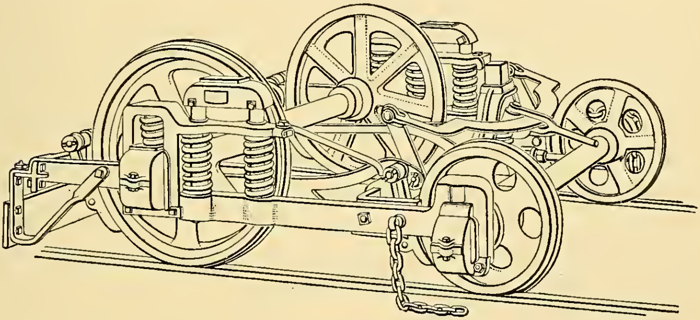


FIG. 3.

lower part of the casing. This waste is kept soaked with oil and effects the lubrication in the same manner as on ordinary railway cars. To guard the wheels against obstructions, the **pilots** *M*, *M*, Fig. 1, are bolted securely to the frame at a sufficient height from the track to avoid touching the rails.

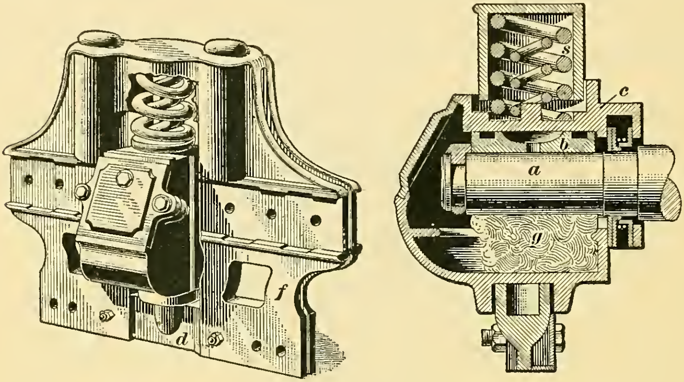


FIG. 4.

7. The **wheel base**, that is, the distance between wheel centers as measured along the rail, should be long enough to support the car body without excessive oscillation, but not so long as to bind on curves. Any car body that calls for a wheel base of over 7 feet should be provided with double trucks. Excessive length of wheel base not only wears out the rails and wheels, but increases the power required to pull the car around a curve. If it takes a pulling force of 500 pounds to pull an 8-ton car with a 7-foot wheel base around a curve whose radius is 50 feet, it will take a pulling force of only 350 pounds to pull the same car around the same curve on a 4-foot base. To pull the same car around a curve of 100 feet radius on a 7-foot wheel base would take a pull of 255 pounds, and on a 4-foot base a pull of 185 pounds. The difference in the pull required on the two bases on the 100-foot curve is much less than it is on the 50-foot curve, which goes to show that the greater the radius of the curve, the less difference does it make what the wheel base is. It is evident, then, that in laying out a road, all the curves should be made of as great a radius as possible; and in buying trucks for a road already installed, the radii of existing curves should be consulted. To enable cars to round curves with the least effort and to save the rails and flanges, curves should be kept clean and well greased. Other points to be considered are in regard to the treads and flanges of the wheels; on them depends very much the ease with which a car will take a curve. The treads should not be so wide that they run on the paving outside of the track, and the shape, depth, and width of the wheel flange should be governed by the shape, depth, and width of the rail groove.

ELECTRICAL EQUIPMENT.

8. The electrical equipment of a trolley car includes several different devices. Some of these, such as the motors, controllers, etc., are concerned directly with the operation of the car. Others—for example, the lightning arrester, fuse box, and hood switches—are more in the line of protective devices. Before considering these various parts in detail, we will glance briefly at the general equipment of a car by referring to Fig. 5. This shows an ordinary 18- or 20-foot car with the details of the truck omitted, in order to show the location of the motors m, m_1. Practically all trolley cars are equipped with at least two motors, and many of the larger cars using double trucks are equipped with four motors. The method of speed control now in use requires at least two motors, as will be shown later. The two motors m, m_1 are hung on the inside of the two axles and geared to them as shown at a, a_1. The speed of the motors, and hence that of the car, is controlled by means of the two **controllers** c, c_1 mounted against the dash irons i, i and operated by the handles n, n_1. When starting the car, it is necessary to insert resistance in the circuit to prevent too great a rush of current. This resistance is only in a short time and is not supposed to be used when the car is under headway. The **resistance boxes** *r* are hung under the car, wherever there is the most room for them, usually about in the location indicated, for an ordinary single-truck car. The **lightning arrester** *L A* and **fuse box** *F B* are generally attached to the under side of the car sill. The **hood switches,** or **canopy switches,** are mounted under the hood, as shown at *s*, *s*. In case circuit-breakers are used in place of ordinary hood switches, they are generally placed at *s*, *s* and the fuse box is dispensed with. The **trolley pole** *p* is attached to the **trolley base** *t*, which is secured to the top of the car. The car is lighted by lamps *l*, *l*, *l* and is heated by means of electric heaters *h*, *h* placed under the seats.

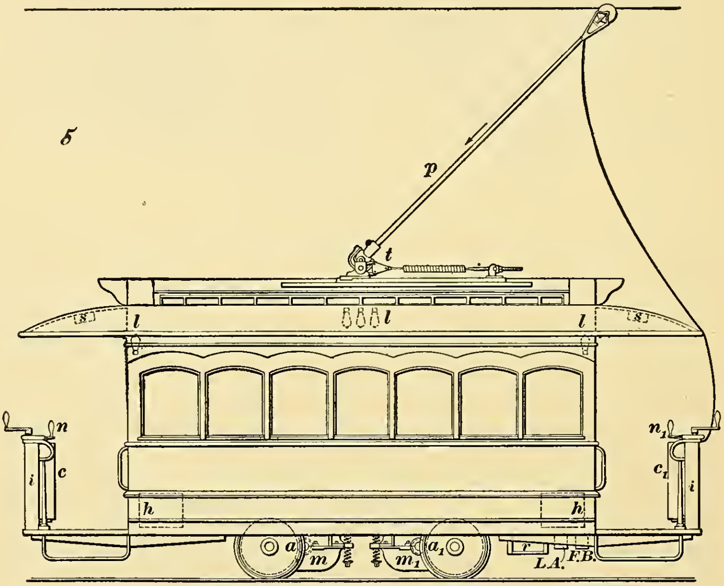


FIG. 5.

METHODS OF CONTROL.

9. It has already been shown that the speed of a motor may be controlled by inserting resistance in series with the armature, thus cutting down the E. M. F. applied to the machine. Before going any farther, it will be well to lay stress on the points that trolley cars are supplied with current at approximately constant pressure, also that the motors used are invariably series-wound. In other words, the armature and fields are in series with each other and the current that flows through one flows through the other also. Shunt motors and compound-wound motors have never been used to any extent for street-railway work.

RHEOSTATIC CONTROL.

10. Since the speed of a series motor run from constant-potential mains may be regulated by inserting a resistance in series with it, the first method adopted for regulating the speed of cars was to mount a **rheostat,** or variable resistance, under the car and have things arranged so that this resistance could be cut in or out by means of the controller at either end of the car. This is known as the **rheostatic** method of control. It can be used with one or more motors, but it is now very little used for regular street-railway work, because it is wasteful of power, especially at the lower speeds. It has, however, some advantages, and it is used in those cases where only one motor is to be controlled and where gradual variations in speed are desired. It is used quite extensively in connection with mine-haulage plants and hoisting apparatus; also for any cars operated by a single motor; but its application to regular street-railway work is now very limited.

On account of the somewhat extended use of rheostatic control in connection with haulage and hoisting apparatus, some of its more important features will be considered briefly. This will also serve as a good introduction to the more widely used series-parallel method, which will be described later.

11. Old-Style Thomson-Houston Rheostat.—When the rheostatic control was first introduced, a rheostat similar to that shown in Fig. 6 was used. The figure shows the device upside down from the position it occupies on a car. *F*, *F*, *F* are feet cast on the frame; these feet are drilled and provided with insulating bushings, through which pass the three bolts that secure the frame to the under part of the platform. *T* is a drum on which works a chain attached to a sprocket wheel connected to a rod on the upper end of which rests the controller handle. The sprocket wheel is smaller than the drum, so that in order to move the trolley contact shoe *S* from the off-position *O* to the on-position *L*, it is necessary to give the controller handle from two to three complete turns. This insures a smooth handling of the car and makes the controller easy to work. *R* is the resistance, which is made up of stampings of sheet iron insulated from one another by sheets of mica. The iron stampings are not entirely insulated from one another, but are sufficiently longer than the mica sheets to allow

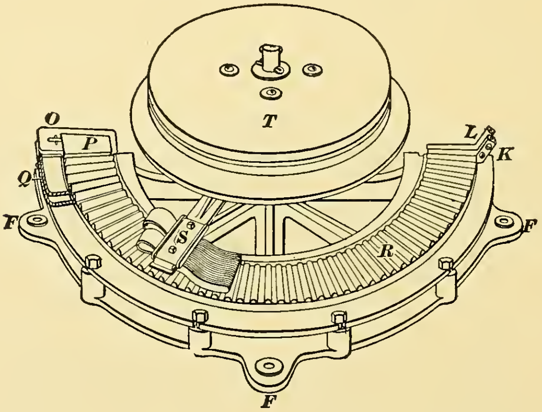


FIG. 6.

their ends to touch, thus forming a continuous band of metal with several hundred joints in it; the radial rib-like-looking segments sticking up so plainly are iron castings built up with the stampings and mica plates, and are provided in order that the shoe *S* may make good contact. At (*a*), (*b*), and (*c*), Fig. 7, are shown, respectively, the iron stamping, the mica plate, and the cast-iron contact rib. *K*, Fig. 6, is a copper rib that marks the position in which the shoe cuts all resistance out of the rheostat; *L* is a second copper rib that cuts a shunt into circuit as soon as it makes contact with the shoe. These two ribs *L* and *K* are made of copper to improve the shoe's contact in the final or running position, the two forming a kind of copper cradle for the iron shoe to rest in. *P* is an iron contact plate at the off-position, to improve the magnetic circuit excited by the blow-out coil *Q*, and is provided to extinguish the arc that occurs when the current is shut off.

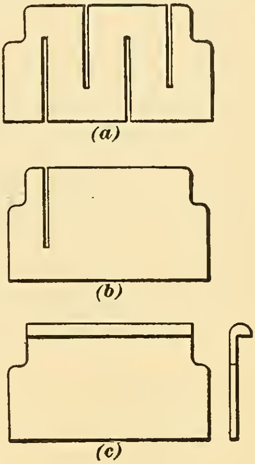


FIG. 7.

12. In addition to the rheostat, it is necessary to provide a reversing switch, so that the direction of motion of the car can be reversed when desired. Fig. 8 shows the connections for simple rheostatic control using an ordinary **reverse switch,** as the reversing switch is commonly called. This switch is operated by a handle on each platform, and the reverse switch and its connections should always be arranged so that when the handle of the reverse switch points "ahead," the car will move ahead, and *vice versa*. In Fig. 8, *T* is the trolley; *F B*, the fuse box; *L A*, the lightning arrester; *T'*, the trolley connection on the rheostat; *S*, the contact shoe that makes contact first with plate *P*, and can be moved around on resistance *R* between the limits of plate *P* and terminals *K* and *L*; *F* is the motor field; *X*, the reverse switch, to the two top binding posts of which the armature *A* is connected; *G* is the ground wire, to which are connected the ground splices from the reverse switch and from the lightning arrester. When *S* makes contact with *P*, the ordinary path of the current is *T–F B–L A–T′–S–P–R–K–F–2–3–A–4–1*, through the ground wire, to the ground at *G*. If the rheostat arm is turned around until the shoe *S* reaches the dotted position *S′*, and that part of the resistance that has been passed over, marked *r*, cut out, a larger current passes through the motor, making it run faster and giving the car greater speed; if the contact shoe is still farther advanced until it reaches the dotted position *S″* and touches the contact plate *K*, all the resistance in *R* is cut out, the path of the current is *T–F B–L A–T′–S″–K–F–2–3–A–4–1* to *G*, and the motor runs at its greatest speed. If the reverse switch *X* is moved over to the dotted position, it is easily seen that the direction of the current through the armature will be reversed, while that in the field will remain the same. The direction of motion will, therefore, be reversed, because it must be remembered that in order to reverse the direction of motion of a motor, either the field or armature may be reversed, but

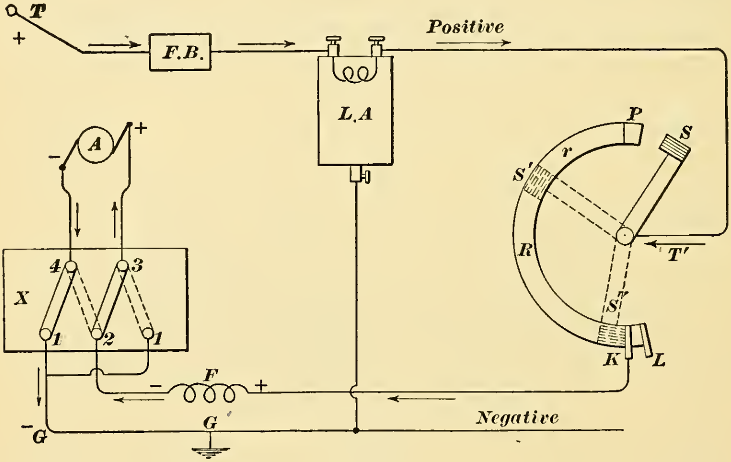


FIG. 8.

not both. It would do just as well to reverse the current through the field and leave that through the armature the same, but it is generally the practice to reverse the current in the armature.

13. Shunt Control.—The method of control shown in Fig. 8 is sometimes called **full-field control,** in order to distinguish it from what is known as **shunt control.** In Fig. 8, when the car is running at its highest speed, all the resistance is cut out and all the current flows through the field *F*. If a still higher speed is desired, it can be obtained by weakening the field of the motor. The weaker the field, the faster an armature has to run to generate the counter E. M. F.; hence, weakening the field increases the speed, but the motor, of course, takes more current. This weakening can be accomplished either by cutting out part of the field turns or by placing a resistance in shunt with the field, thus depriving the field coils of part of the current.

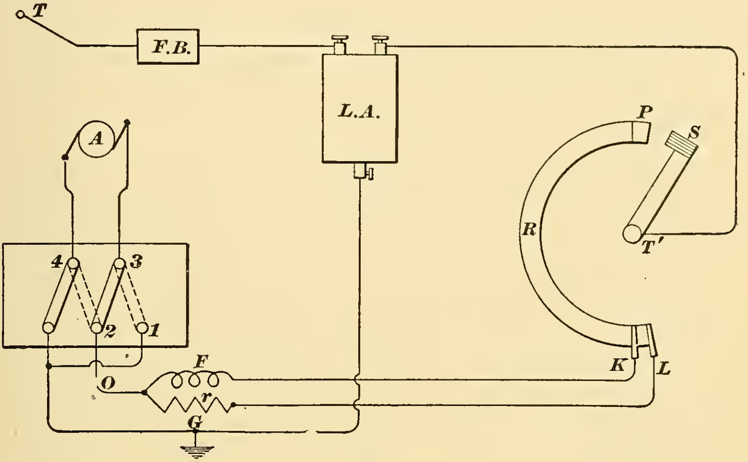


FIG. 9.

Fig. 9 shows the connections of the shunt method of control as carried out by means of a rheostat. Here a resistance or shunt *r* is connected to one terminal of the field, and the other end is connected to plate *L* on the rheostat.

When the shoe rests on both *K* and *L*, the current, in order to get to point *O*, passes through two paths that are in multiple; path *K–F–O* includes the field and path *L–r–O* includes the shunt. As the shunt generally measures about three times as much as a warm field, it takes away from the field one-third the total current. It must be borne in mind that the final result of bringing the shunt into action is to increase the speed of the car, and the car cannot be made to go faster under given conditions without being furnished with more power; this increase in power is provided by the increase in the current due to the weakening of the motor field by the shunt. The use of shunts was at one time quite common, but it is not so generally followed now. The latest equipments are not provided with shunts, because it is found that all the speed control that is necessary can be obtained without them, and their use only leads to complication and opens up chances for trouble.

14. Use of Platform Controller.—The old-style rheostat, Fig. 6, was soon replaced by the platform controller. It was found that the movable arm on the rheostat under the car gave considerable trouble, so the next step was to place the resistance itself under the car and run wires from it and the motors to a controller placed on the platform. The controller is a device for cutting out the resistance or for effecting any combinations necessary for the control of the speed. Many kinds of controllers are made to meet different conditions of service. Fig. 10 shows how the movable arm of the rheostat may be replaced

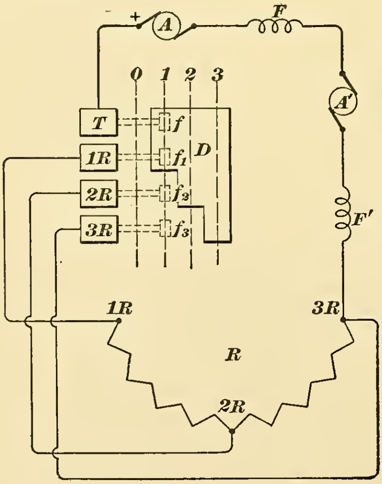
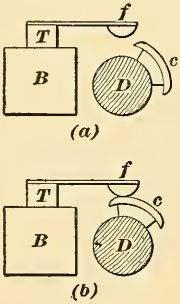


FIG. 10.

by a simple controller and also how the cutting out of resistance is effected. R is a resistance divided into two parts; one part lies between $1R$ and $2R$ and the other part between $2R$ and $3R$; F and A are the field and armature, respectively, of a dynamo that is to furnish the current for running the motor whose field and armature are F' and A'; D is a round casting fitted on a wooden drum provided with an iron shaft that turns in bearings. This casting is here shown as straightened out flat, although it is really cylindrical in shape. T, $1R$, $2R$, and $3R$, in the upper part of the figure, are brass finger stands, on each of which is a finger, hanging over D, as indicated by the dotted lines and marked in the figure f, f_1, f_2, f_3. A wire is connected to each of the finger stands. Stand T is connected to the trolley wire; stands $1R$, $2R$, and $3R$ are connected to the resistance coil at points marked with the corresponding letters. On this controller there are four notches, indicated by the dotted lines, marked *0*, *1*, *2*, *3*. The line marked *0* denotes the off-position, and no current can pass through the circuit, because the trolley finger f hangs in the air, as shown in Fig. 11 (*a*), without touching the contact plate c mounted on the drum D. Dotted line *1* denotes the first notch, and fingers f and f_1 touch the contact plate on drum D, as shown in Fig. 11 (*b*). The circuit being, therefore, closed, the current can flow through the path $A-T-f-D-f_1-1R-1R-2R-3R-F'-A'-F-A$. Dotted line *2* denotes the second notch where the drum is turned until finger f_2 makes contact; the path of the current is then $A-T-f-D-f_2-2R-2R-3R-F'-A'-F-A$. On the second notch, when the current gets to drum D, it finds two paths by means of which it can reach point $2R$ on the resistance coil; one path is $f_1-1R-1R-2R$, and the other path is $f_2-2R-2R$. The first path has a part of the resistance coil in it and the second path (i. e., car wire $2R-2R$) has very little resistance. Wire $2R-2R$ then short-circuits the $1R-2R$ part of



(*a*)

(*b*)

FIG. 11.

the resistance. When the drum is turned another notch, and finger f_3 comes into contact, the path of the current is $A-T-f-D-f_3-3\ R-3\ R-F'-A'-F-A$. Wire *3 R–3 R* short-circuits the whole resistance in *R* and the motor runs on full field directly across the line, just as it does in Fig. 8, when *S* touches *K*. This controller gives a means of cutting out resistance, but the cutting out is not as gradual as where the rheostat arm is used. It is found, however, in practice that three or four resistance notches are sufficient to give a car a smooth start if the controller is handled properly.

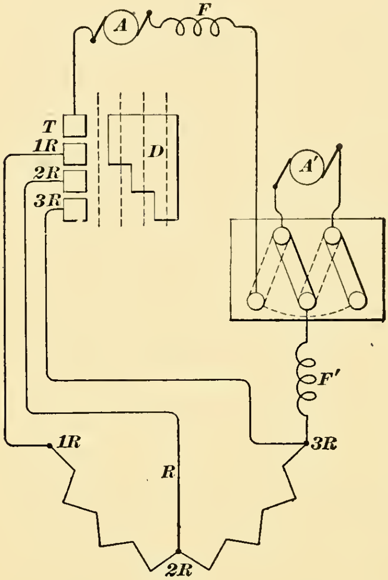


FIG. 12.

15. Fig. 12 shows how an ordinary reversing switch might be used with a simple controller of this kind. However, in modern controllers it is the practice to have the reversing switch also made in the form of a drum and to mount it in the same case with the power drum.

RHEOSTATIC CONTROLLER.

16. General Construction.—Fig. 13 shows a modern type of rheostatic controller designed by the General Electric Company for the control of cars, haulage locomotives, or hoisting motors. This controller is considered somewhat in detail because it contains many of the features found on controllers used on street cars and will serve as a good introduction to the study of them. The controller shown in Fig. 13 is designed to handle one 50-horsepower 500-volt motor or one 25-horsepower 220-volt motor, i. e., its contacts are large enough to handle about 75 amperes. The figure shows the cover *A* thrown back so as to expose the working parts. This controller is of the *magnetic blow-out type*, and is known as a type R controller because it uses rheostatic control. In the General Electric Company's controllers, a magnetic field is used to extinguish the arc that would otherwise form at the contact tips and cause blistering and burning. This method of preventing arcing has proved very effective. *B* is the coil that sets up the magnetic field necessary to blow out the arc, and is therefore called the **blow-out coil.** The iron back of the

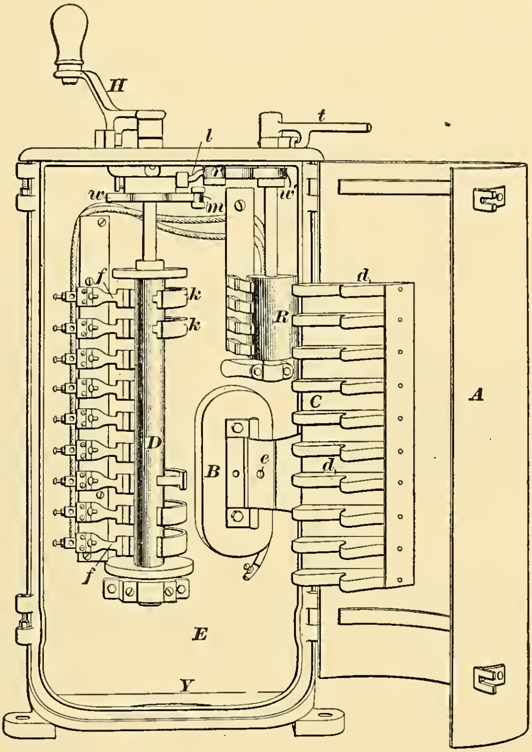


FIG. 13.

controller forms one pole piece and the polar extension *C* the other. Pole piece *C* is shown swung back so as to give access to the **power drum** *D*. When the controller is in use, the pole piece *C* is swung over and held in position by a bolt passing through hole *e*. Fig. 14, although not drawn to scale, will give an idea as to the relation of the pole piece *C*, drum *D*, and the controller back *E* when the pole piece is swung into position. The pieces *d* are **arc guards,** and are made of vulcabeston (vulcanized asbestos); they pass between the contact arcs and prevent arcing between the contacts. The whole of the current supplied to the car passes through blow-out coil *B* and sets up a magnetic field between *N* and *S*, as indicated by the curved dotted lines.

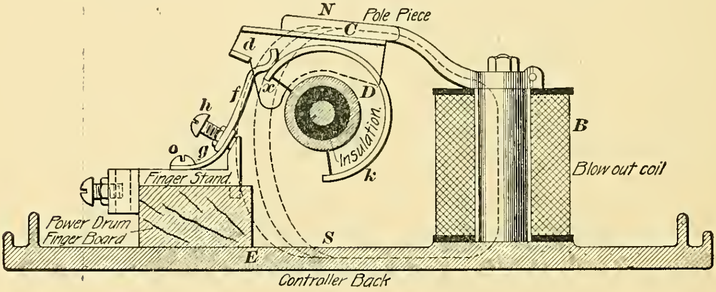


FIG. 14.

When the drum is revolved far enough, the tip *x* of contact arc *k* leaves finger *f* and an arc tends to form. This arc acts in the same way as a flexible wire carrying current, i. e., it is forced across the field just as the conductors on the armature of a motor are forced to move on account of the reaction of the magnetic field set up around the wire on the field supplied by the field magnets. In this case, the arc is forced across the field and stretched out until it is broken. The action is practically instantaneous, so that there is little or no burning of the fingers and contact arcs. The fingers *f* are stamped out of thick copper and are fastened to a flat phosphor-bronze spring *g*, which is in turn fastened to the cast-brass finger stand by means of screws *o*, so that fingers may be replaced at any time. The screw *h* is for adjusting the amount that the finger drops when the drum passes from under it. This affects the pressure with which the fingers press on the drum, and they should be adjusted so as to drop about $\frac{1}{32}$ to $\frac{1}{16}$ inch. The contact arc *x k* should frequently be rubbed with a little vaseline so as to prevent wear and cutting.

17. Star Wheel, or Index Wheel.—The power drum is operated by means of the power handle *H*, Fig. 13, which fits on the top of the power-drum shaft. In order to compel the power drum to take up a definite position corresponding to the various steps, it has a **star wheel,** or **index wheel,** *w* attached to the shaft. This engages with a spring-actuated roller *m*, which is pulled into the various notches on the star wheel and forces the drum into its proper position. It is this star wheel and roller that gives the movement of a controller handle its springy feeling.

18. Reverse Drum.—The reversing switch, or reverse drum, as it is called, is shown at *R*. This is a much smaller and simpler drum than the power drum, and it is mounted in the upper right-hand corner of the controller. Its sole function is to reverse the armature connections in case it is desired to run the car in the opposite direction. It is not intended to turn the current on or off or effect any changes in the resistance. For this reason, the reverse drum is not provided with any device for suppressing arcing, and its contact fingers are somewhat lighter than those on the power drum.

19. Interlocking Device.—In order to make sure that the reverse switch shall not be moved while the current is on, the controller is provided with an interlocking device, that makes it impossible to move the reverse drum unless the power drum is at the off-position. The reverse drum shaft is provided with a star wheel *w'* having three notches, corresponding to the off-, ahead-, and back-positions. The lever carrying the roller *r* that engages this star wheel has a link *l* attached to it, which runs across to the hub of the star wheel *w*. The hub of *w* has a notch in it that comes opposite the end of *l* when the power drum *D* is at the off-position, and when the reverse handle *t* is moved, the end of link *l* is forced over into the notch until the roller *r* passes over the projection on the star wheel *w'*, when *l* falls back far enough to allow *D* to be turned. At any position of *D* other than the off-position, there is no notch opposite the end of *l*; hence, when an attempt is made to move *t*, the link *l* comes up against the hub and the reverse drum is locked.

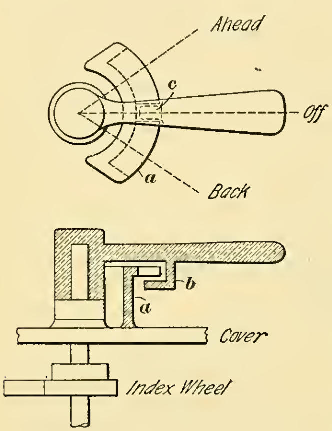


FIG. 15.

When the reverse lever points ahead, the car runs forwards, and when it points back, the car runs backwards.

The reverse handle is also arranged so that it cannot be removed until the power drum is at the off-position. An **L** guard *a*, Fig. 15, is cast on the controller cap and overhangs a hook *b* cast on the handle. A notch *c* is cut in the guard, so that the handle can be lifted off at the off-position and no other.

One of the principal reasons for this interlocking arrangement is to make sure that the motorman will not reverse the motors while the power is on. In time of danger, the first thing the motorman would naturally do would be to reverse or "plug" the motors. If this were done, the counter E. M. F. of the motors, instead of opposing the line E. M. F., would be added to it and would assist the line E. M. F. in forcing an exceedingly large current through the motors, and, to make matters worse, there would be no resistance in series with the motors. The effect would be the same as a very bad short circuit; in all probability the main fuse would be blown, thus leaving the car helpless, so far as reversing the motors is concerned. If the cylinders interlock, the motorman first has to throw off the power, then throw the reverse switch. When the power is thrown on again, the resistance will be cut into circuit and there will be much less danger of damage being done.

20. Operation of Rheostatic Controller.—The foregoing will give the student an idea as to the mechanical construction of a controller of this type. The controller has six points, and a development of the drum with the various connections is shown in Fig. 16. This diagram shows a single motor, of which A' and F' are the armature and field, respectively. It is operated by a single controller. In this

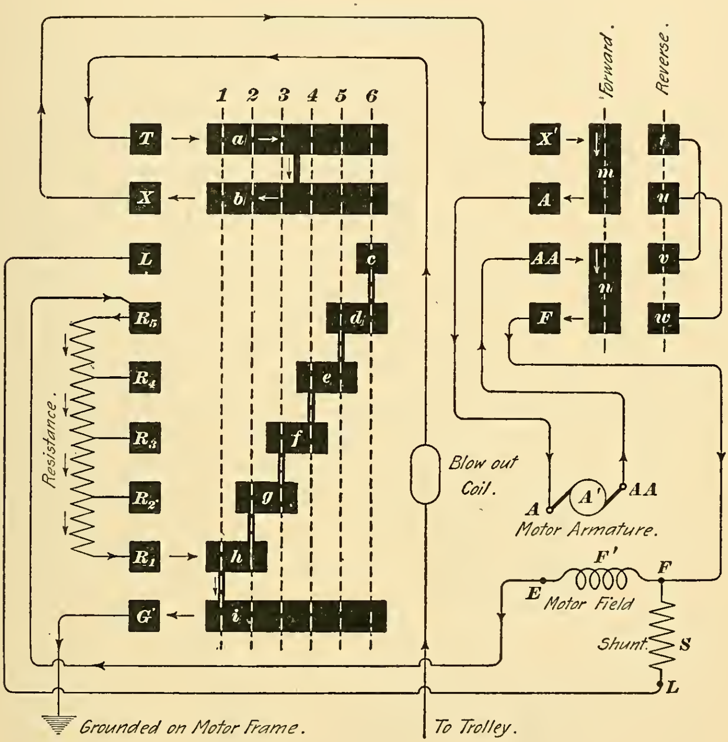


FIG. 16.

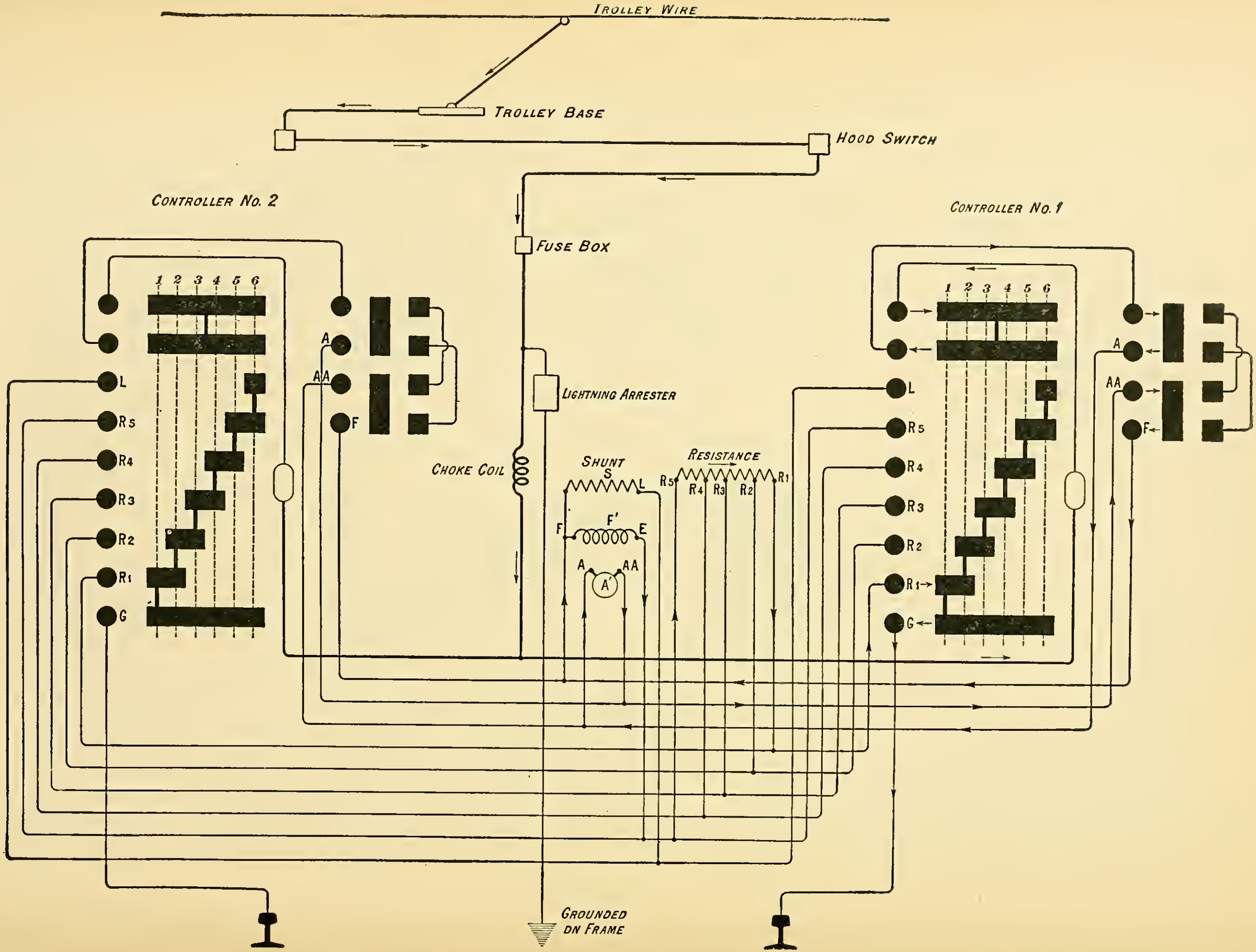

TROLLEY WIRE
TROLLEY BASE
HOOD SWITCH
CONTROLLER NO. 2
CONTROLLER NO. 1
FUSE BOX
LIGHTNING ARRESTER
CHOKE COIL
SHUNT
S
RESISTANCE
L
R5
R4
R3
R2
R1
F
F'
E
A
AA
A'
G
1 2 3 4 5 6
GROUNDED ON FRAME

FIG. 17.

controller figure and in those to follow, the drum contact arcs are indicated by black bands, which represent the arcs straightened or developed out flat. The finger stands on the power drum, and on the reverse drum connection boards are represented by the row of square black spots. The vertical dotted lines represent the various positions of the drum. Note that the drum is in two parts. Contact arcs a and b are connected together, but these two are insulated from c, d, e, f, g, h, and i, which are all connected together, because they constitute a single casting. On the first notch, fingers T, X, R_1, and G make contact with their respective arcs. All the others hang over and touch nothing.

The path of the current on the first notch is indicated by the arrows, and is as follows: Trolley–blow-out coil–T–a–b–X–X'–m–A–A–armature A'–AA–AA–n–F–F–field F'–E–R_5–through the whole of the resistance–R_1–h–i–G to ground, thus completing the circuit from the trolley to the rail.

On the second notch, finger R_2 touches arc g, and when the current reaches R_5, it flows through three sections only of the resistance, because when it reaches R_2, it takes the path R_2–g–h–i–G. On the third notch, the section of resistance between R_2 and R_3 is cut out. On the fourth notch, that between R_3 and R_4, and on the fifth notch all the resistance is cut out, and the path of the current is: trolley–blow-out coil– T–a–b–X–X'–m–A–A–A'–AA–AA–n–F–F–F'–E–R_5–d–e–f–g–h–i–G. The fifth notch, then, gives the highest speed that can be attained by simply cutting out resistance.

On this controller a shunt S may be used and a sixth notch is provided, so that on this notch the shunt will be connected across the motor field coil, thereby weakening the field and increasing the speed. One end of this shunt is attached to F and the other end to finger L. On the sixth notch, the path of the current is the same as on the fifth notch up to the point F; here the current divides, part of it taking the path F–F'–E–R_5–d–e–f–g–h–i–G, and the other part the path F–S–L–L–c–d–e–f–g–h–i–G, thus taking part of the current away from the field.

21. Operation of Reverse Switch.—If the motor is to be reversed, the reverse switch is thrown over, bringing contacts *t*, *u*, *v*, *w* under fingers *X'*, *A*, *AA*, and *F*, respectively. When the current reaches *X'*, it takes the path *X'*–*t*–*v*–*AA*–*AA*–*A'*–*A*–*A*–*u*–*w*–*F*. In other words, it flows in at the *AA* end of the armature instead of at the *A* end as before, but it still flows in at the *F* end of the field, thus reversing the current through the armature, but not through the field. The lettering of the various connecting posts in the controller is that used by the General Electric Company.

22. Car With Two Rheostatic Controllers. — In Fig. 16, only one controller is shown, in order to simplify matters, but on a car or mining locomotive two controllers, one on each end, are usually necessary. Fig. 17 shows two of these controllers connected together and operating a single motor with the parts arranged in about the relative positions they would occupy on the car. The corresponding connecting posts of the two controllers are connected together by the long wires that run the length of the car. These wires are sometimes called **hose wires,** because they are usually in the form of stranded copper cables run in canvas hose. In some cases, however, the wires are run separately and fastened to a board by means of cleats. Of course, when one controller is in use, the other is at the off-position, because the handle of the reverse switch cannot be removed until the power is thrown off. The arrowheads show the path of the current when controller No. *1* is on the first notch. This is practically the same as that shown in Fig. 16, except that the parts are in a little different location. Notice that the current passes through both hood switches and the fuse box before reaching the controllers. The wires in this diagram, Fig. 17, are not supposed to touch each other where they cross unless there is a round dot placed at their point of intersection. As an exercise, the student should trace out the path of the current on the other points, in order to become familiar with the method of representing the car wiring. The various combinations may be represented diagrammatically, as shown in Fig. 18. The first five steps differ from each other in the amount of resistance included, and the last step is the same as the fifth, with the exception that the field F' is shunted.

When a rheostat is used continuously to control the speed, it must be proportioned so as to avoid overheating, and all the resistance notches may be used as running notches.

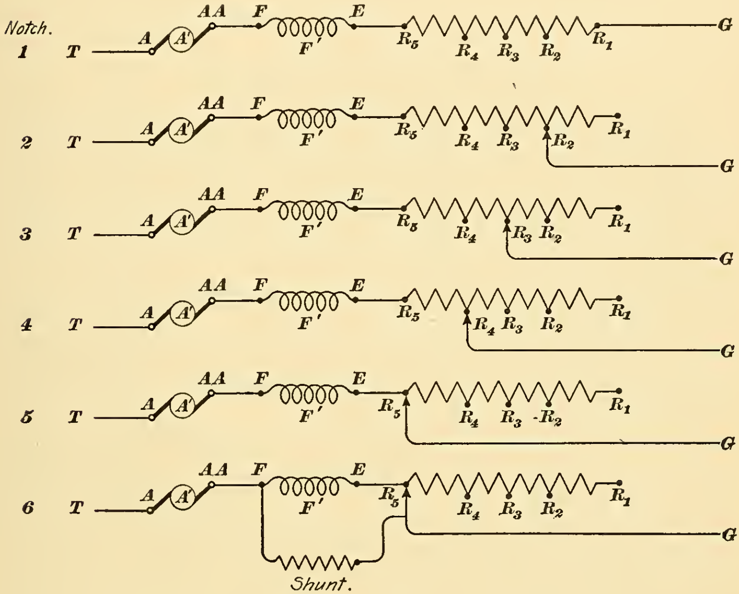


FIG. 18.

With ordinary street cars, however, the resistance is not supposed to be used for speed-controlling purposes. It is only used to give the car a smooth start and should not be used to run on. Before leaving the study of this controller, it may be well to notice that the resistance coils are here placed next to the ground, so that the current first enters the motor. In most controllers the resistance is placed ahead of the motors, but on the whole it makes no difference so far as the effect of the resistance itself goes; it sometimes does, however, make a difference in regard to the amount of trouble that arises on account of grounds occurring on the resistance. Also notice, in Fig. 17, that the post marked *AA* on controller No. *1* is connected to post *A* on controller No. *2*, and post *AA* on controller No. *2* is connected to post *A* on controller No. *1*. This is done in order that the car may always run forward when the reverse handle on the end from which it is run points ahead.

SERIES-PARALLEL CONTROL.

23. General Description.—The method of speed control now almost universally used for street-railway work is known as the **series-parallel** method. It enables the voltage applied to the motors to be cut down for slow-speed running without the use of resistance, and hence is more economical on low speeds than the rheostatic method. At least two motors per car are required. For slow speed, these motors are connected in series, and for high speed, they are connected in parallel; hence, the name series-parallel applied to this system of control.

Since the motors are designed to operate normally on 500 volts—that is, when supplied with this pressure across their terminals they will run at their maximum speed—let us assume that the pressure furnished is 500 volts. Then, if the two motors on a car are connected in series, as shown in Fig. 19, it is evident that the pressure across each motor will be only 250 volts. Each motor will then have to run at only about half its normal speed to generate the required counter E. M. F., and the result is that a slow speed is obtained without the use of any resistance.

When the higher speed is desired, the controller is thrown around to the "multiple notches" and effects the combinations necessary to change the motors from series to parallel. When they are in parallel, as shown in Fig. 20, each motor gets its full voltage of 500 and runs at full speed. Of course, at starting it is necessary to include some resistance, and when changing from series to multiple, resistance is also cut in to prevent excessive rushes of current and to give a smooth acceleration to the car; but this resistance is cut out as soon as the car gets under headway and is not to be used on the running notches.

A great many types of series-parallel controller have been brought out, and it would be an endless task to describe all of them. All that is necessary here is to show their principles of operation, because if the student understands these thoroughly, he should have little difficulty in tracing out any ordinary car-wiring diagram. The diagrams of car wiring are usually furnished by the controller makers to those that use their apparatus.

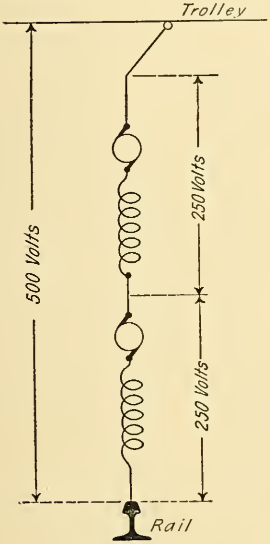


FIG. 19.

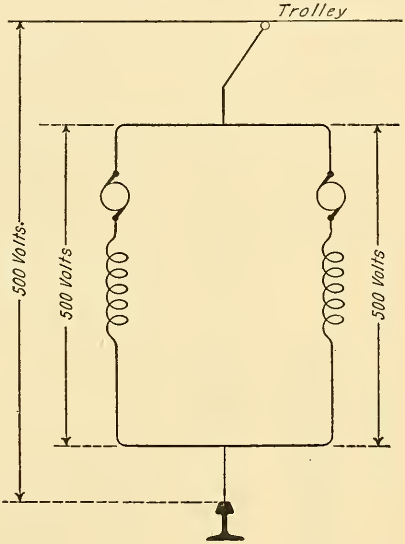


FIG. 20.

K2 SERIES-PARALLEL CONTROLLER.

24. General Description.—The type K2 series-parallel controller brought out by the General Electric Company is one that has been very widely used on electric railways.

The General Electric Company make several styles of what they designate as the type K controller. They are, however, the same in general construction and principles of operation. In all the type K controllers one of the motors is shunted or short-circuited during the change from series to parallel, otherwise the designation "type K" has no special significance. The type K controllers embody many of the features already described in connection with the type R controller. The magnetic blow-out is arranged in the same way, and the general mechanical construction is the same, though, of course, the type K is more complicated, because it must handle all the connections for two motors and effect the changes necessary to throw the motors from the series to the parallel arrangements. It is also provided with switches, by means of which either of the motors may be cut out, in case one of them becomes disabled, allowing the car to be operated on the other motor. The K2 controller is designed for use with shunts, i. e., on the last series notch the fields of both motors are shunted and the same is also the case on the last multiple notch.

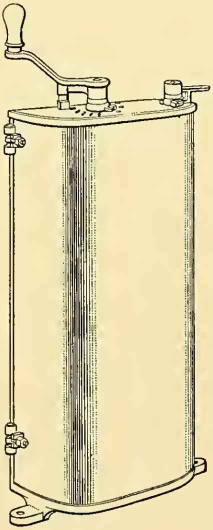


FIG. 21.

The K2 controller is used on motors of 35 horsepower or under and has nine notches. There are more positions than this, but only nine of them are marked on the controller top, and the mechanism of the controller is so fixed that the handle cannot be easily made to rest anywhere except on a marked notch. This is done so that the drum will not hang between notches and cause burning inside the controller. Fig. 21 shows the K2 controller with the door closed, as it appears on the end of a car; Fig. 22 shows the door opened so that the inside parts may be seen.

In Fig. 22, *1* is the controller handle that turns the controller or power drum *2*; *3* is the reverse handle that turns the reverse drum *4*; *9*, *9* are the fingers or wipers that make contact with the power drum; *6* is the blow-out magnet. The reverse drum and its fingers have no blow-out coil.

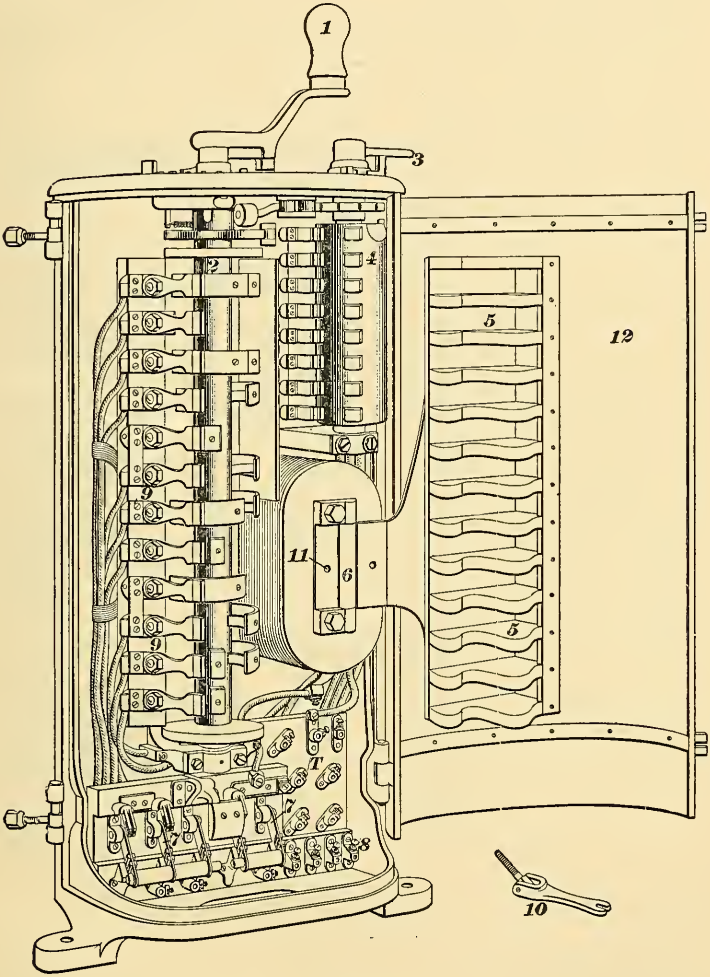


FIG. 22.

because the reverse drum cannot be moved while the current is on, and there is, therefore, no arc there to be put out. *7*, *7* are the **cut-out switches**, by means of which a disabled motor may be cut out; *8* (in the lower right-hand corner) is the **connection board,** into which all wires run from the motors and other devices, as well as the ground and trolley wires. The terminals on the connecting board also connect to the various parts of the controller, as will be shown later

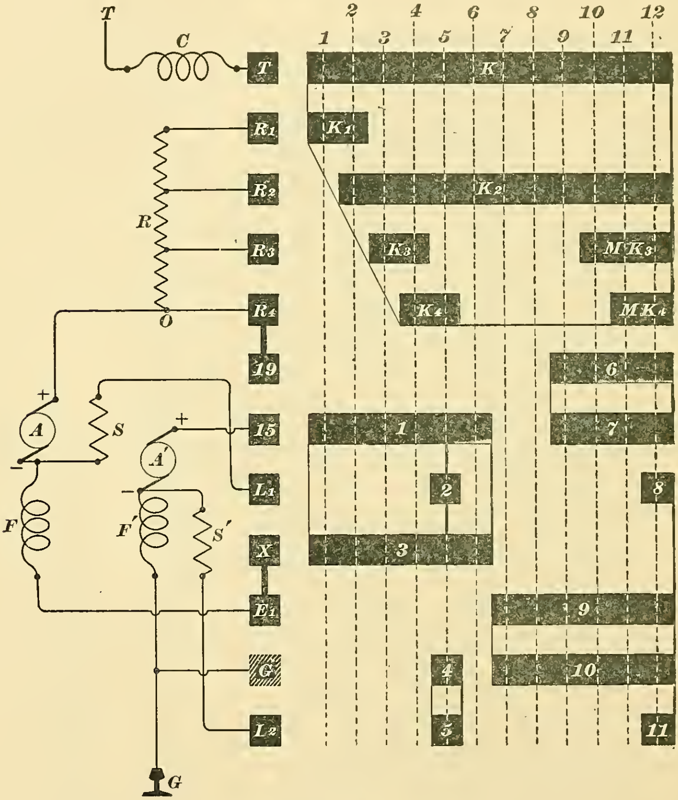


FIG. 23.

in another diagram. *12* is the door, or cover, that swings back as shown, and *10* is the bolt and wrench used for holding the pole piece in place when it is swung over; *5*, *5* are the arc guards, mounted in the way previously described. It will be noticed that both the power drum and the reverse drum of this controller are longer than those of the rheostatic controller. The interlocking device between the two drums is practically the same on both, but the connection board *8* is made necessary on account of the numerous connections and the addition of two cut-out switches *7*, *7*.

25. Fig. 23 shows the K2 controller with the power drum fully laid out, but the reverse switch, the motor cut-outs, and the controller connections are omitted for the present, in order to simplify matters. The letters used on the controller fingers are the same as those used on an actual controller. T is the trolley finger; R_1, R_2, R_3, R_4 are the resistance fingers. F and A are the field and armature of the No. 1 motor; F' and A' are the field and armature of the No. 2 motor; S is the No. 1 shunt and S' the No. 2 shunt. E_1 is the free end of the No. 1 motor field, and the free end of No. 2 motor field is grounded. L_1 is the free end of the No. 1 shunt S around the field F of the No. 1 motor, the other end being spliced to one end of the No. 1 motor field. L_2 is the free end of the No. 2 shunt, the other end being spliced to one end of the No. 2 motor field. G is the ground finger; *15* and *19* are fingers that ordinarily take wires running from the reverse switch, but as the reverse switch is left out, the wires are in this case run direct. There are twelve positions, as indicated by the twelve vertical dotted lines, but there are only nine notches. Three of the positions the motorman knows nothing about, further than that he can feel a change take place when the controller handle is swept over these positions in going from series to parallel.

26. The **first position** is the first notch; the two motors are in series and the whole of the starting coil is in the circuit. The **second position** is the second notch; the two motors are in series and part of the starting coil is cut out. The **third position** is the third notch; the motors are still in series, but more of the starting coil is cut out. The **fourth position** is the fourth notch. The motors are still in series, but the whole of the starting coil is cut out. The upper part of the drum simply looks after the cutting out of the resistance. The lower drum segments (those numbered) look after the changing from series to parallel and the cutting in of the shunts S and S'. The path of the current on the fourth notch is $T-C-T-K-K_4-R_4-A-F-E_1-X-3-1-15-A'-F'-G$.

The **fifth position** is the fifth notch. The motors are in series, all the starting coil is cut out and each field has a shunt in multiple with it. As soon as the fifth notch is reached, three drum plates *2*, *4*, and *5* and three new fingers L_1, G, and L_2 are brought into action. It must be borne in mind that one end of S is spliced to one end of F and one end of S' is spliced to one end of F'. As soon as L_1 touches plate *2*, the free end of S makes contact, through $L_1-2-3-X-E_1$, with the negative end of F, and as soon as L_2 and G touch plates *5* and *4*, the free end of S' and the grounded end of F' are brought together, with the result that when the current reaches point $A-$, it splits and gets to finger *15* through two paths: $A--S-L_1-2-1-15$ and $A--F-E_1-X-3-1-15$. When the current gets to point $A'-$, it reaches the ground in two ways: $A'--S'-L_2-5-4-G$ and $A'--F'-G$. The general path of the current on the fifth position, then, is $T-C-T-K_4-R_4-A-\left\{\begin{matrix}F-E_1-X-3-1-15\\ S-L_1-2-1-15\end{matrix}\right\}-$ $A'-\left\{\begin{matrix}F'-G\\ S'-L_2-5-4-G\end{matrix}\right\}$ and to the rail.

27. The **sixth position** is not a notch, but is one of the series of combinations used in passing from series to parallel. It must be noticed that the K2 drum plate, Fig. 23, runs nearly across the drum and that none of the other series-position drum plates touch their respective fingers after the fifth notch is passed. The effect of this is to cut resistance into the circuit again as soon as the drum leaves the fifth position, with the result that the sixth position is the same as the second; i. e., the two motors are in series, have full fields, and that part of the starting coil that lies between R_2 and R_4 is in the circuit. The path of the current, then, on the sixth position is $T-C-T-K-K_2-R_2$, through the two lower sections of the resistance coil R, and through $A-F-E_1-X-3-1-15-A'-F'-G$. There is no mark on the controller top to show where the sixth position is.

28. The **seventh position** is one of transition, and is not a notch. As the drum leaves the sixth position and goes to the seventh, plates *3* and *1* pass out of service and plates *9* and *10* pass into service; the effect of plates *3* and *1* going out of action is to drop the No. 2 motor out of the circuit entirely, because the field end of the motor goes to the ground and the $A'+$ end of the motor goes to finger *15*, which hangs in the air as soon as plate *1* passes from under it, and the motor can get no current. But the coming into action of plates *9* and *10* gives the current a new path in place of the one that was broken. The path of the current on the seventh position is $T-C-T-K-K_2-R_2-R-A-F-E_1-9-10$ to the rail G. On the seventh position, then, one motor has been dropped out of the circuit and the car runs on the No. 1 motor in series with two sections of the starting coil. Just at the instant that the fingers are midway in their passage from the sixth position, finger E_1 touches plate *9* at the same time that finger X, to which E_1 is connected, touches plate *3*, with the result that No. 2 motor is momentarily short-circuited, through $A'+-15-1-3-X-E_1-9-10-G-F'-A'-$, just before it is cut out of circuit; but this cannot be felt, because there is so much of the starting coil in ahead of both of the motors.

29. The **eighth position** is the same as the seventh position, and it is not a notch. No new plates are cut into action and no old ones are dropped. The eighth position is a useful one, however, in that it gives the drum a greater distance to travel in its passage from the series to the multiple positions.

30. The **ninth position** is the sixth notch. The two motors are in multiple, have full fields, and are in series with two sections of the starting coil. The arrival of the drum on the ninth position brings plates *6* and *7* into action, and enables the No. 2 motor to get current through finger *15*. The current divides between the two motors at the point *O* where the resistance wire splices on to the *A*+ armature wire; from there to the ground are two paths; one of them is O–A–F–E_1–9–10–G and the other path is O–R_4–19–6–7–15–A'–F'–G. The ninth position is a marked notch, but is not a running notch.

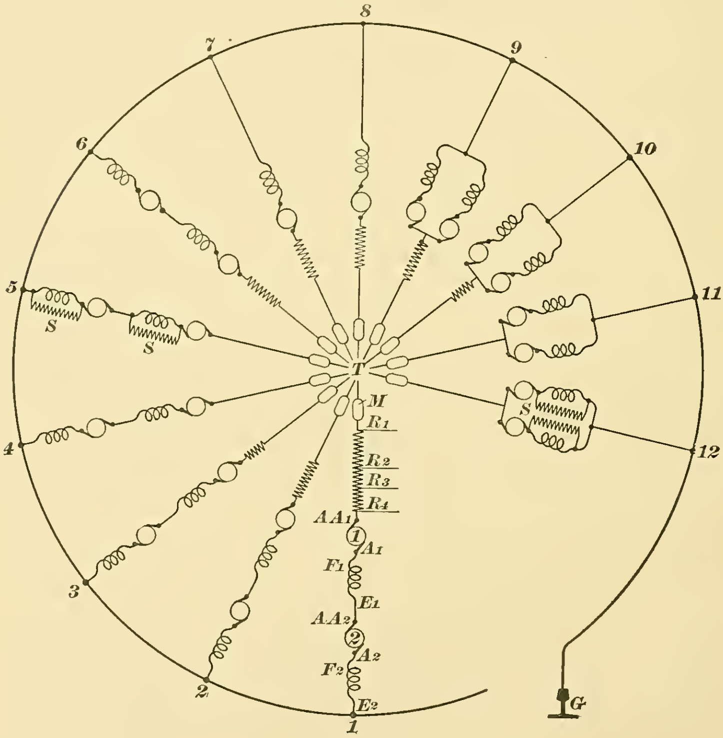


FIG. 24.

31. The **tenth position** is the seventh notch, but it is not a running notch. The two motors are in multiple and are in series with but one section of the starting coil, because finger R_3 touching plate MK_3 cuts out that part of the coil that lies between R_2 and R_3.

32. The **eleventh position** is the eighth notch and is a running notch. The motors are in multiple, have their full fields, and all the starting coil is cut out of the circuit.

33. The **twelfth position** is the ninth notch, which is also a running notch. The ninth notch is the same as the eighth notch, excepting that plates *8* and *11* coming into action put shunts on both the motor fields. The combinations at the various positions are indicated by the diagrams in Fig. 24.

34. The Notches.—On the top of every controller will be found some small ribs, which, in conjunction with the pointer carried on the power-drum shaft, enable the motorman to tell when the drum is on a notch. On controllers of some makes, this pointer is cast on the handle itself, but this is not a good plan, because as soon as the fit between the handle and the shaft becomes loose, the pointer indicates wrongly. Beside the ribs or dashes on the top is usually found the word "off," to indicate the off-position of the drum.

35. Some of the ribs on top of a controller are long and some of them are short. The long ribs indicate the notches on which it is safe to run any length of time; the short ribs indicate the notches to be used only in starting and in going from series to parallel. On the K2 controller there are four of these long ribs; two of them are for the series combination and two for the multiple. The two long ribs in series

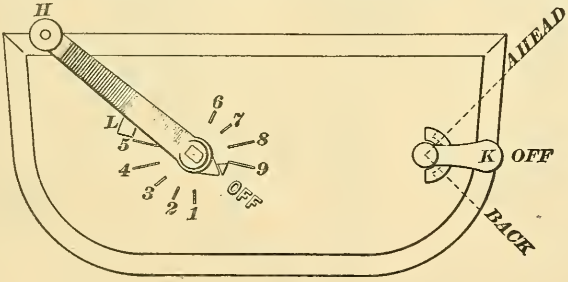


FIG. 25.

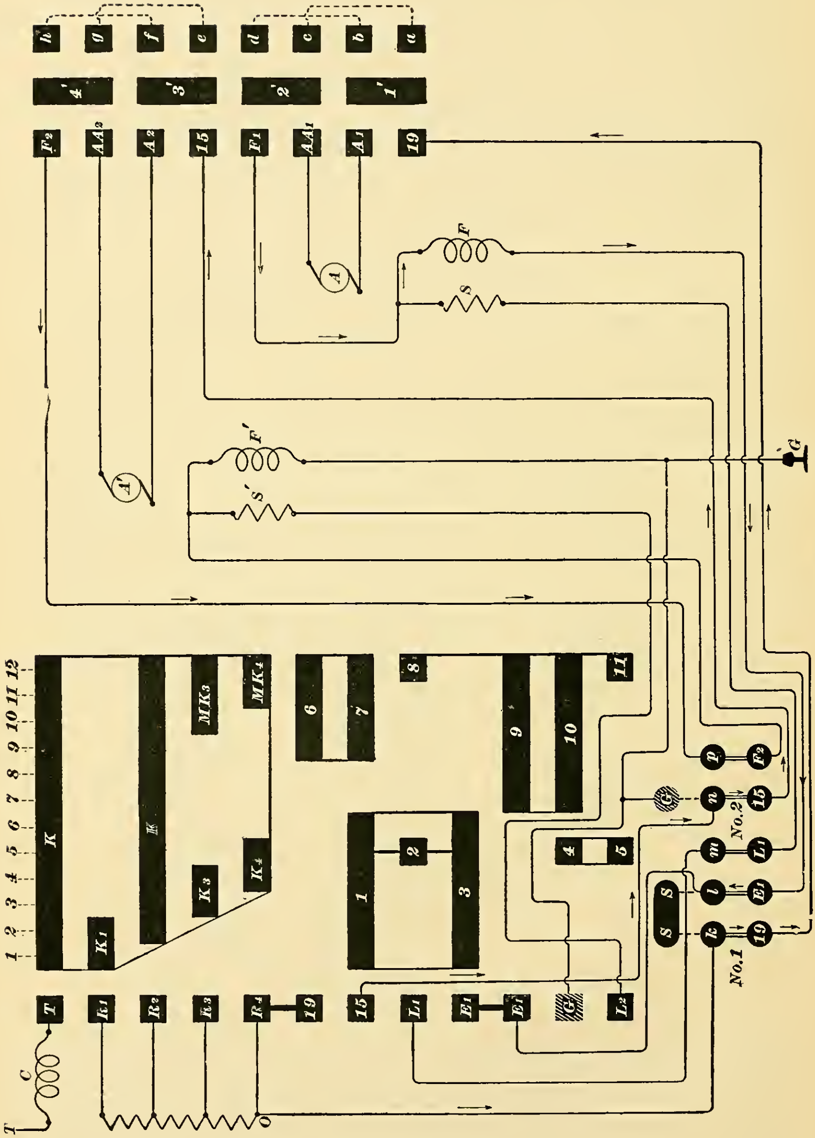

h
g
f
e
d
c
b
a
4'
3'
2'
1'
F2
AA2
A2
15
F1
AA1
A1
19
F
S
A
F'
S'
A'
G
1 2 3 4 5 6 7 8 9 10 11 12
K
K1
K
MK3
MK4
K3
K4
6
7
8
9
10
11
1
2
3
4
5
S
S
p
n
m
l
k
F2
15
L1
E1
19
G
No.2
No.1
T
R1
R2
R3
R4
19
15
L1
E1
E1
G
L2
C
T
O

FIG. 26.

indicate the fourth and fifth notches; those in multiple indicate the eighth and ninth notches. The K2 controller has, then, four running notches: the fourth, fifth, eighth, and ninth, and none of the other notches should be run on for any length of time, for it is a waste of power and an abuse of the starting coil.

36. Fig. 25 shows the layout of the K2 controller top. *H* is the power-drum handle resting on the off-position; *K* is the reverse handle, also at the off-position. If *K* is moved ahead, the car will move ahead as soon as *H* is moved until its pointer points to *1*; if *K* is moved back, the car will move backwards. *L* is a lug against which a projection on the handle bears when the handle is moved to the ninth notch or to the off-position. On old-time types of controllers, it was necessary to watch the pointer very carefully to avoid running in between the notches, thereby burning the controller tips and fingers, but on modern controllers, the roller that plays into the notches on the drum index is acted on by a spring that is strong enough to force the drum around as soon as the roller begins to descend into a notch.

37. **Reverse Drum.**—The reverse drum of the K2 controller is similar in construction to that used on the R controller, except that it is provided with twice as many contact plates and fingers, in order to accommodate the two motors. This switch is shown in the upper right-hand corner of Fig. 26. When the car runs "ahead," the fingers of the reverse switch rest on plates *1'*, *2'*, *3'*, *4'*; when it runs "back," they rest on *a*, *b*, *c*, etc., thus reversing the current through the armatures *A* and *A'*, as previously explained.

38. **Motor Cut-Out Switches.**—In the lower part of the K2 controller, just below the power drum, the two motor cut-out switches are located. These are seen at 7, 7, Fig. 22, and are marked No. *1* and No. *2* in Fig. 26. This figure shows the controller complete, with the exception of the connection board. As mentioned before, the two motor cut-out switches are used to run the car on one motor if the other motor or any part of its circuit gives out. These two switches may be thrown up or down, and when the car is in good shape and both motors in use, both switches should be down. Inside the door of every K2, K10, or K11 controller is found a card that tells how to cut out a faulty motor; one motor is called the No. 1 motor and the other the No. 2 motor; the No. 1 motor is the motor on the fuse-box end of the car. Inside the No. 1 controller, the card reads: "*To cut out motor No. 1* (*the motor nearest this end of car*), *throw up left-hand switch as far as it will go. To cut out motor No. 2* (*motor nearest other end of car*), *throw up right-hand switch as far as it will go.*" Inside the No. 2 controller, the card reads: "*To cut out motor No. 1* (*motor nearest other end of car*), *throw up left-hand switch as far as it will go. To cut out motor No. 2* (*motor nearest this end of car*), *throw up right-hand switch as far as it will go.*" The motor cut-out instruction cards read differently on the two ends of the car, because on the front end the No. 1 motor is the front motor and the No. 2 motor is the rear motor; but on the rear end the No. 2 motor is the front motor and the No. 1 motor the rear motor.

39. The shaft of the power drum has on it a stop that is interfered with by a pin operated by the cut-out switch in such a way that when either switch is thrown up, the power drum cannot be moved past the fifth notch. If this were not done, the result would be simply to drop the motor out of circuit when leaving the sixth position and pick it up again on the ninth position if the good motor happened to be the No. 1 motor. If the good motor happened to be the No. 2 motor, as soon as fingers E_1 and G made contact with plates *9* and *10*, Fig. 26, there would be a dead short circuit across the line. The way in which this occurs will be shown later.

40. In Fig. 26, the blades of switch No. *1* are hinged to posts k, l, and m; those of switch No. *2* are hinged to n and p. When switch No. *1* is thrown up, posts k and l are connected by the strip $S S$, and post m is dead-ended because the blade attached to it simply overhangs. When switch No. *2* is thrown up, post n is connected with the ground post G and post p is dead-ended.

41. In Fig. 26, both switches are thrown down, so that both motors are cut in and the path of the current on the first notch is $T-C-T-K-K_1-R_1-O-k-19-19-1'-A_1-A-AA_1-2'-F_1-F-E_1-l-E_1-E_1-3-1-15-n-15-15-3'-A_2-A'-AA_2-4'-F_2-p-F_2-F'-G$. If the No. *1* switch is thrown up to the dotted position, the No. 1 motor is cut out and the path of the current is $T-C-T-K-K_1-R_1-O-k-SS-l-E_1-E_1-3-1-15-n-15-15-3'-A_2-A'-AA_2-4'-F_2-p-F_2-F'-G$. If the No. *2* switch is thrown up to the dotted position (No. *1* switch being down), the No. 2 motor is cut out and the path of the current becomes $T-C-T-K-K_1-R_1-O-k-19-19-1'-A_1-A-AA_1-2'-F_1-F-E.-l-E_1-E_1-3-1-15-n-G-G$.

42. If by any chance both switches should be thrown up, thereby cutting out both motors, the path of the current would be $T-C-T-K-K_1-R_1-O-k-SS-l-E_1-E_1-3-1-15-n-G-G$. The resistance coil alone would be in circuit, the car could not start, and any advance of the power handle would cause the main-motor fuse to blow unless some part of the controller should blow first. Such an act as cutting out both motors at the same time is an unusual one, but still it has happened with bad results. It must be clearly understood that a cut-out switch should be used only when the power is off. The switch is not built to break any arc, and any attempt to make it do so is apt to result in not only the destruction of the switch itself, but in injury to the operator's eyes.

The cut-out switches on controllers made by different companies vary somewhat in detail and appearance, but they all drop the motor out of the circuit entirely and put a metal path in its place, so that the current has a bridge over which it can cross in order to reach the motor that is not to be cut out.

43. Car-Wiring Diagram for K2 Controllers.—Fig. 27 shows a complete car-wiring diagram for two K2 controllers. W is the trolley wheel, K, K the hood switches, $F\ B$ the fuse box, $L\ A$ the lightning arrester. When the No. 1 controller is on the first notch, the path of the current is: $W-K-K-FB-$choke coil$-O-T-M-T-R_1-R_1-r_1$ through all the resistance $-r_4-R_4-t-19-19-19-1-A_1-A_1-A_1-AA_1-AA_1-AA_1-2-F_1-F_1-F_1-E_1-E_1-E_1-E_1-E_1-c-15-15-15-15-3-A_2-A_2-A_2-AA_2-AA_2-AA_2-4-F_2-F_2-F_2-F_2-E_2-G$. The end E_2 of the No. 2 field is permanently connected to the ground wire. The student should, as an exercise, trace out the paths of the current on the other notches, which are indicated by the dotted vertical lines. The fourth and fifth and the eighth and ninth are the running notches. On the fifth and ninth notches the fields are shunted. In Fig. 27, the wire marked "test line" has nothing to do with the regular controller connections. It simply illustrates a method of locating breaks in the car wiring by using a number of lamps L. One end of the test line is connected to the trolley and the free end is touched to the various devices in succession so that the lamps will indicate when the break has been passed.

K11 SERIES-PARALLEL CONTROLLER.

44. Fig. 28 shows the appearance of the K11 controller. This controller is a great deal like the K2, but has two distinguishing features. Its contacts are of larger current capacity, the controller being designed for use with 50-horsepower motors, whereas the K2 controller is intended for use with 35-horsepower motors. The K11 controller is also intended to be used with motors that do not require a shunt, and it is provided with one more resistance notch than the K2. The K2 controller uses a three-part resistance, whereas the K11 resistance has four parts. The K2 controller can handle motors with or without the shunt, the shunt wires being simply left out where no shunts are used, but on

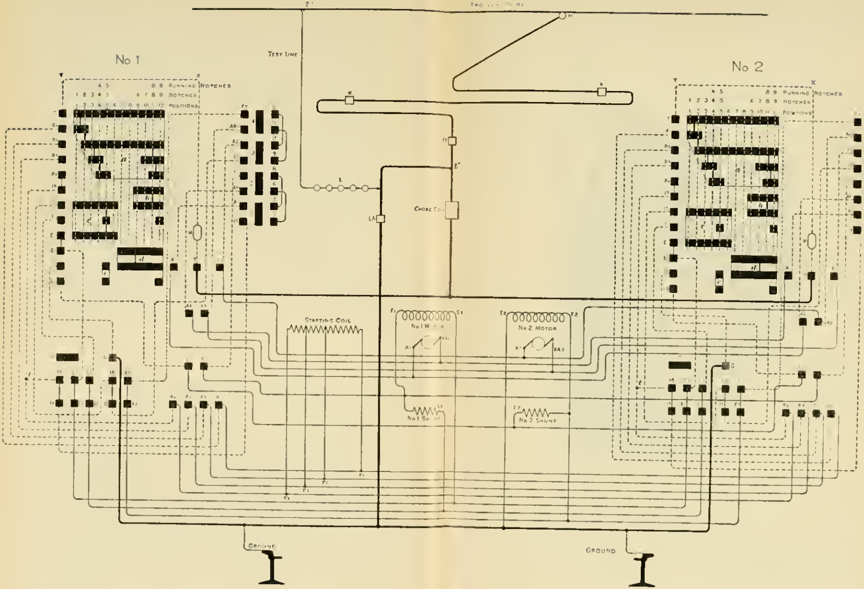

Trolley Wire
Test Line
No 1
No 2
Running Notches
Notches
Positions
L
LA
Choke Coil
Starting Coil
No 1 Motor
No 2 Motor
No 1 Shunt
No 2 Shunt
Ground
Ground

Fig. 27

the K11 controller there are no shunt fingers or connecting-board blocks provided, so that a shunt cannot be used unless

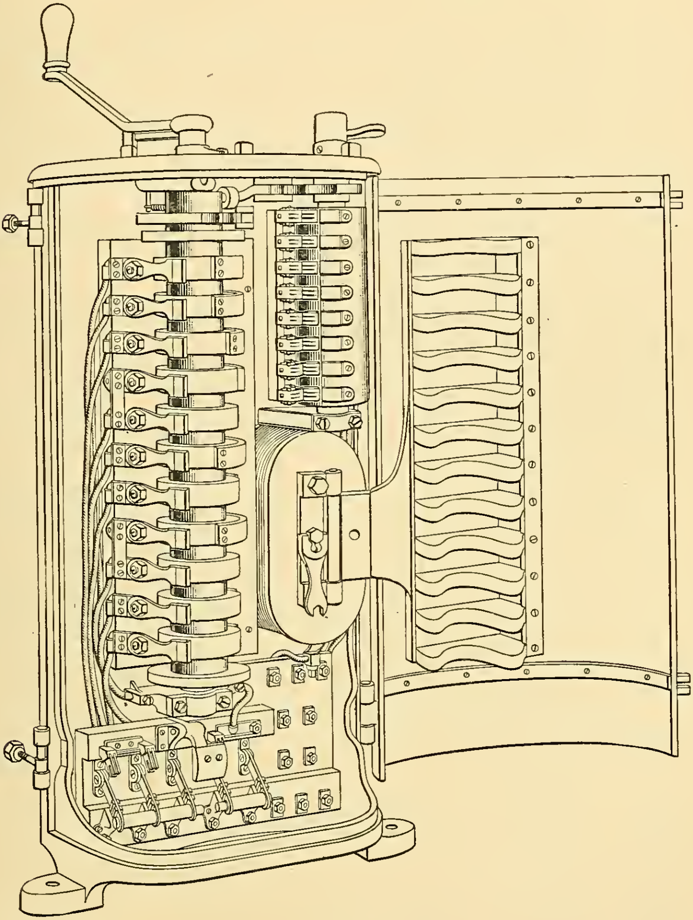


FIG. 28.

both ends of it are permanently spliced to the two field terminals.

45. Fig. 29 gives the combinations effected on all positions of the power drum. There are five notches in series

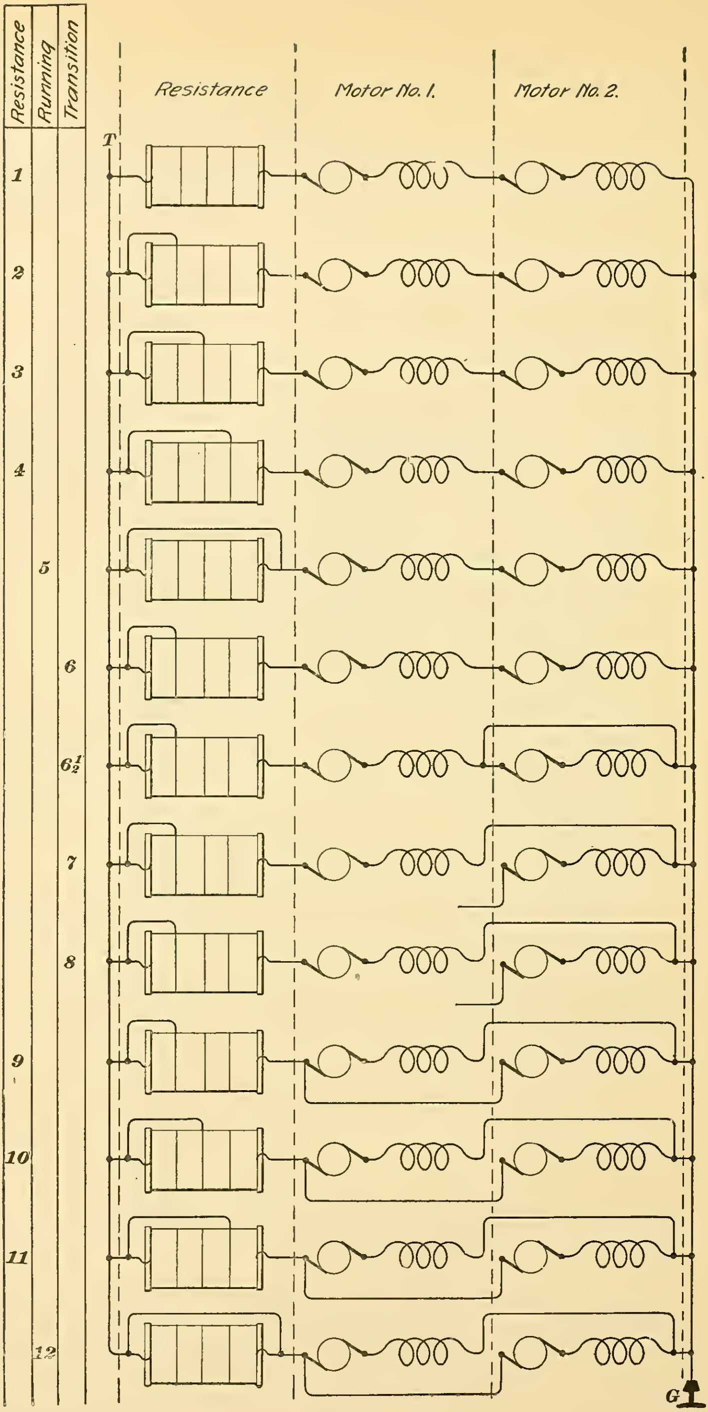

Resistance
Running
Transition
Resistance
Motor No. 1.
Motor No. 2.
T
1
2
3
4
5
6
6½
7
8
9
10
11
12
G

FIG. 29.

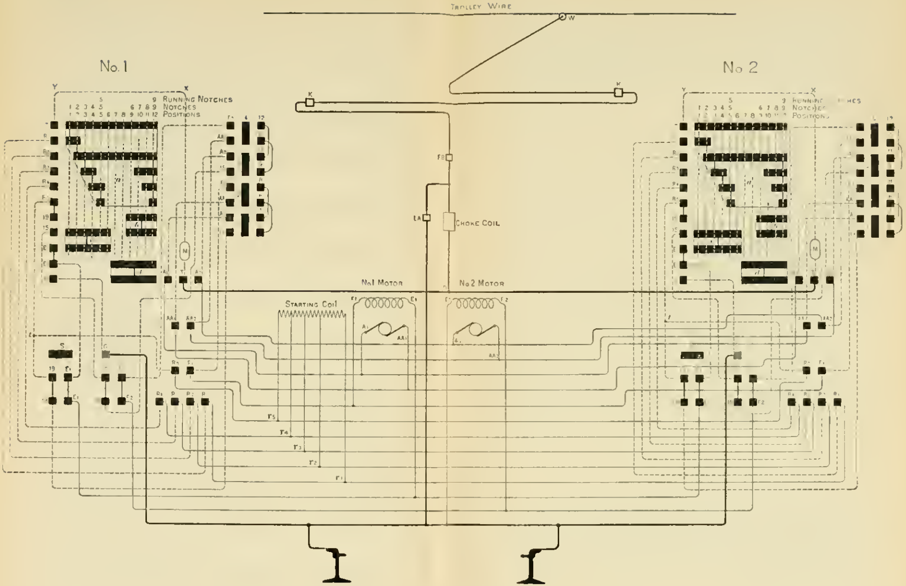

Trolley Wire
W
K
K
FB
LA
Choke Coil
No. 1
No. 2
Y
X
Running Notches
Notches
Positions
1 2 3 4 5 6 7 8 9 10 11 12
R
R2
R3
R4
F
19
15
E
M
a
b
c
A1
T
A2
AA1
AA2
No. 1 Motor
No. 2 Motor
F1
E1
F2
E2
Starting Coil
S
G
19
E1
E2
R3
P
R2
R
r5
r4
r3
r2
r1

FIG. 30

and four notches in multiple, making a total of nine notches, the same as on the K2 controller. But where the K2 controller has four running notches, two in series and two in multiple, the K11 has only two running notches, one in series and one in multiple. These two running notches are the fifth and ninth.

K10 CONTROLLER.

46. The K10 controller is practically the same in appearance as the K2 and is designed for the same class of work. It has replaced the K2 largely, because shunts are not now used as much as they once were, and the K10 is designed for use without shunts. In fact, it makes the same combinations as the K11, so that Fig. 29 may be taken to represent the various steps. It is a lighter controller than the K11 and is used with 35-horsepower motors. It has four resistance notches, and therefore gives the car a somewhat smoother acceleration than the K2. Fig. 30 shows the car-wiring diagram for two K10 controllers. By comparing with Fig. 27, the student will see that the diagrams are very similar. There is one more section in the starting coil and the shunts are omitted, thus simplifying the controller and its connections to a considerable extent. The running notches are the fifth and ninth. On the fifth notch the motors are in series and all the resistance is cut out and on the ninth they are in parallel and all the resistance is cut out.

WESTINGHOUSE 28A CONTROLLER.

47. The Westinghouse Company has manufactured several types of series-parallel controller that differ considerably in detail from those just described. They now supply controllers of the General Electric type, but quite a large number of their older styles are still in use. We will describe the

28A controller. Fig. 31 shows the Westinghouse No. 38 controller, which is very similar in appearance to the 28A. The different sections of the power drum are separated from each other by vulcabeston insulating rings *U*, *U*, *U*, etc., as

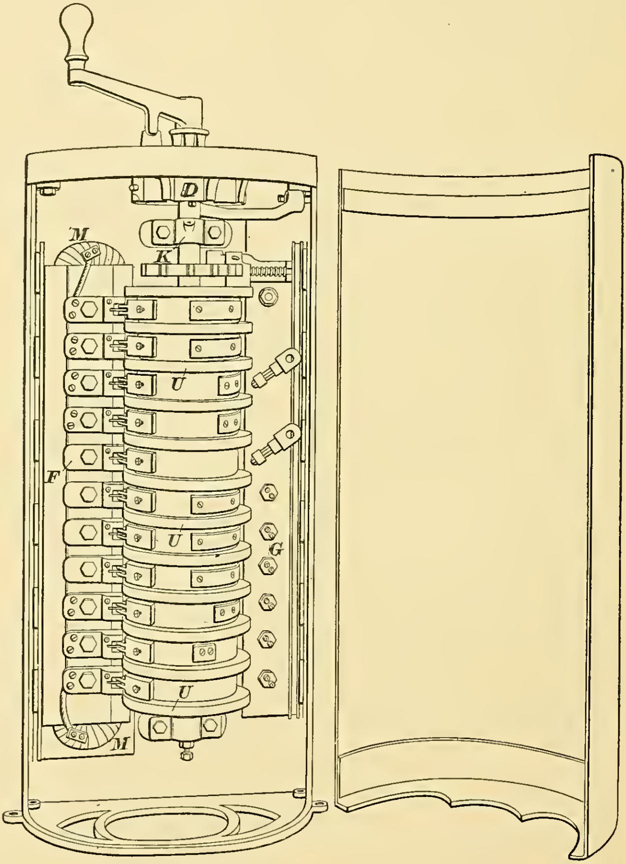


FIG. 31.

shown in Fig. 31. The reverse device, shown at *D*, is of the disk form instead of the drum type, as in the General Electric Company's type K2. The power-drum finger board is on the left at *F*. Around the base of the finger board is wound a magnetic blow-out coil *M*, which, by way of fingers that contain a great deal of iron, projects lines of force across the arc gaps and extinguishes the arcs. The connecting board is in two sections; one section is at *G* in the right-hand part of the controller and the other is in the lower part, below the power drum. As is the case with all modern controllers, the 28A motor cut-outs are arranged so that when one motor is cut out, there is an interference with the power drum in such a way that it cannot be turned past the series notches. With one motor cut out, the 28A controller starts the car on the first notch and gives the single motor full power on the fourth notch. The power and reverse handles interlock as on the K2 and K11 types.

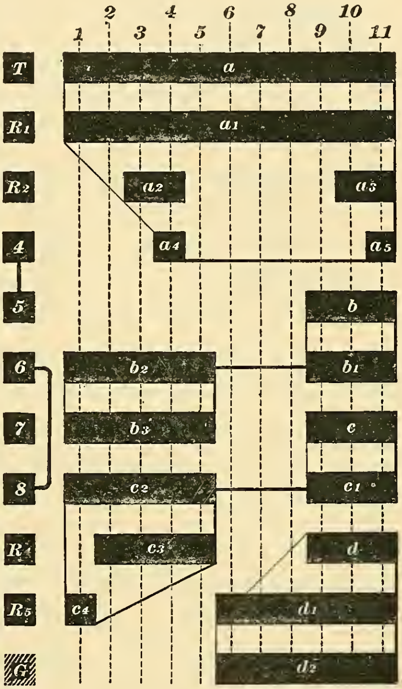


FIG. 32.

48. Fig. 32 shows the 28A power drum and the finger board on the left. This drum has four groups of rings; all rings marked *a* are connected together and should ring up together when tested with a magneto-bell; the same is the case with the rings marked *b*, *c*, and *d*; but groups with different letters are insulated from one another. The vertical dotted lines show the several positions assumed by the drum in going from the first notch to the last one.

49. The 28A Reverse Switch.—On the 28A reverse switch, as on any other, the position of the reverse handle is supposed to indicate the direction in which the car will start as soon as the power drum is turned on.

Fig. 33 shows the connections of the 28A reverse switch. In this diagram, all the devices have been left out save the motors and resistances. All wires, instead of running to their respective controlling devices, as on a car, are here run direct to the reverse switch. The mechanical details of the moving parts of the switch are not shown in Fig. 33, but they can be understood by reference to Fig. 34, which shows the principle on which the switch operates. *D D* is a flat vulcabeston, slate, or fiber disk on the outside rim of which are screwed the brass tips *T*, *T*, *T*, *T*. Handle *H* is pivoted at *O′* and can be moved ahead or back, but in the figure it is in the off-position, in which position it can be taken out. Posts F_1-, A_1+, F_1+, F_2-, A_2-, and F_2+, in Fig. 33, are stationary; besides having connecting posts to which wires can be run, they have switch blades against which brass tips *T*, *T*, *T*, *T*, Fig. 34, press when the handle *H*, and hence the lever *L*, is moved one way or the other. When the handle *H* is shoved ahead to the right, the connections are as shown by the shaded lines in Fig. 33, where F_1+ is connected to post *9*, F_1- to A_1+, F_2+ to post *11*, and F_2- to A_2-. In this position, the path of the current from the trolley *T* to the ground *G* is T–R_1–R_2–R_3–*9* across one of the drum tips to post F_1+, out through the No. 1 motor field, back to post F_1-, across another drum tip to post A_1+, out through the No. 1 motor armature and back through resistance coil R_4–R_5 to post *12*, thence across the dotted line (which indicates that posts *11* and *12* are permanently connected,

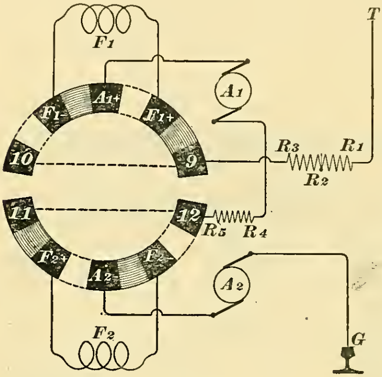


Fig. 33.

as are posts *9* and *10*) to post *11*, through a third drum contact tip to post F_2+, from where it passes out through the No. 2 motor field, back to post F_2-, across the fourth and last drum contact tip to post A_2-, through the No. 2 motor armature to the ground at G. This ground is secured by grounding the negative brush lead of the No. 2 motor directly to the frame of the motor or to the ground wire. If the reverse handle H is thrown back, the drum contact tips take up the position shown by the dotted lines in Fig. 33, and the former connections are broken. Posts F_1- and *10* are connected together, posts F_1+ and A_1+, F_2- and *12*, F_2+ and A_2- are also connected, and the path of the current from the trolley to the ground is $T-R_1-R_2-R_3-9-10-F_1-$, through the No. 1 motor field, F_1+-A_1+, through the No. 1 motor armature, $R_4-R_5-12-F_2-$, through the No. 2 motor field F_2+-A_2-, and through the No. 2 armature to the ground at G, as before.

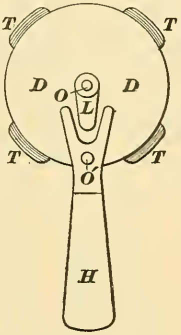


FIG. 34.

50. It should be noticed that when the reverse handle points ahead, the current enters the No. 1 motor field on the right-hand end and the No. 1 armature at the top brush holder; it goes into the No. 2 motor field at the left-hand end and into the No. 2 armature at the lower brush holder. When the reverse handle is thrown back, the current goes into the two armatures the same as it did before, but it goes into the No. 1 field at its left-hand end instead of the right and into the No. 2 field at the right-hand end instead of the left, as it did when the reverse handle was set to send the car ahead. The fields, then, have been reversed instead of the armatures, as on the General Electric equipment.

51. The 28A Cut-Out.—The 28A cut-out consists of two sets of posts, four posts for each motor, with holes in them to take a plug shaped to fit the holes. To operate the cut-out, the plug is taken by the handle, pulled out part of the way, and given a quarter-turn; on releasing the plug, a spring pulls it back home into its new position. The lower plug is for the No. 1 motor, the motor next to the trolley wire, and the upper plug is for the No. 2 motor, the motor next to the ground.

In Fig. 35, both motors are shown cut in, in which position the plugs make contact between the posts that are up and down. For example, the lower plug connects posts *15* and *16* on one side and posts *13* and *14* on the other, the top plug connects posts *17* and *18* on one side and *19* and *20* on the other. Post *20* might just as well not be there, as far as being of any electrical use is concerned, because it is not connected to anything. It is put there not only to avoid having two sorts of cut-out devices in the controller, calling for two sorts of plugs, but it also serves as an additional mechanical support for the top plug, thereby making a good electrical contact more certain. In the position shown in Fig. 35, the path of the current is $T–R_1–R_2–R_3–13–14–F_1+\ –F_1–\ –A_1+\ –A_1–\ –15–16–R_4–R_5–17–18–F_2+\ –F_2–\ –A_2–\ –A_2+$ to the ground at G.

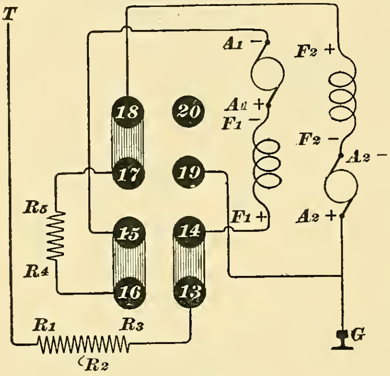


FIG. 35.

It will be noticed that the brush lead at which the current goes into the No. 2 armature is marked $A_2–$. Of course, the very fact that the current goes in at this brush holder makes it positive, but the lead is marked negative to indicate the fact that because the motors hang on the car truck back to back, their armatures must turn in opposite directions, in order to urge the car in the same direction, and if the current goes into both fields from the same end, it must enter the armatures at the front lead on one motor and at the back lead on the other.

52. In Fig. 36 the No. 1 motor is shown cut out; its plug has been given a quarter-turn, breaking all connection between posts *13* and *14*, and making a connection between the lower posts *13* and *16*, thereby leaving the two ends of the No. 1 motor, connected to posts *14* and *15*, hanging in the air, as it were. The No. 1 motor is, therefore, cut out because it can get no current. The path of the current in this case is $T–R_1–R_2–R_3–13–16–R_4–R_5–17–18–F_2+\,–F_2-\,–A_2-\,–A_2+$ to the ground at G.

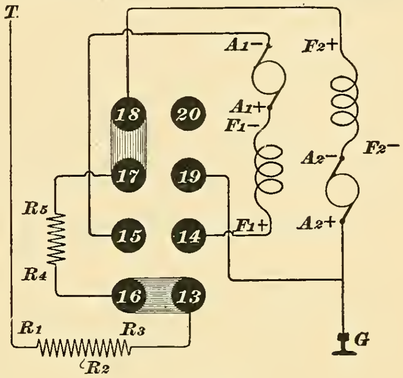


FIG. 36.

53. Fig. 37 shows the No. 1 motor cut in and the No. 2 motor cut out. In this case, a quarter-turn on plug No. 2 has broken the connection between posts *17* and *18* and made connection between posts *17* and *19* direct to the ground at G. One end of the No. 2 motor is left hanging in the air at post *18*, and the other end is grounded through its permanent ground connection. The motor is cut out and therefore dead. The path of the current in this case is $T–R_1–R_2–R_3–13–14–F_1+\,–F_1-\,–A_1+\,–A_1-\,–15–16–R_4–R_5–17–19$ to earth at G.

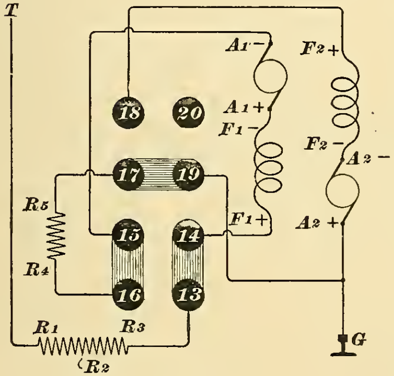


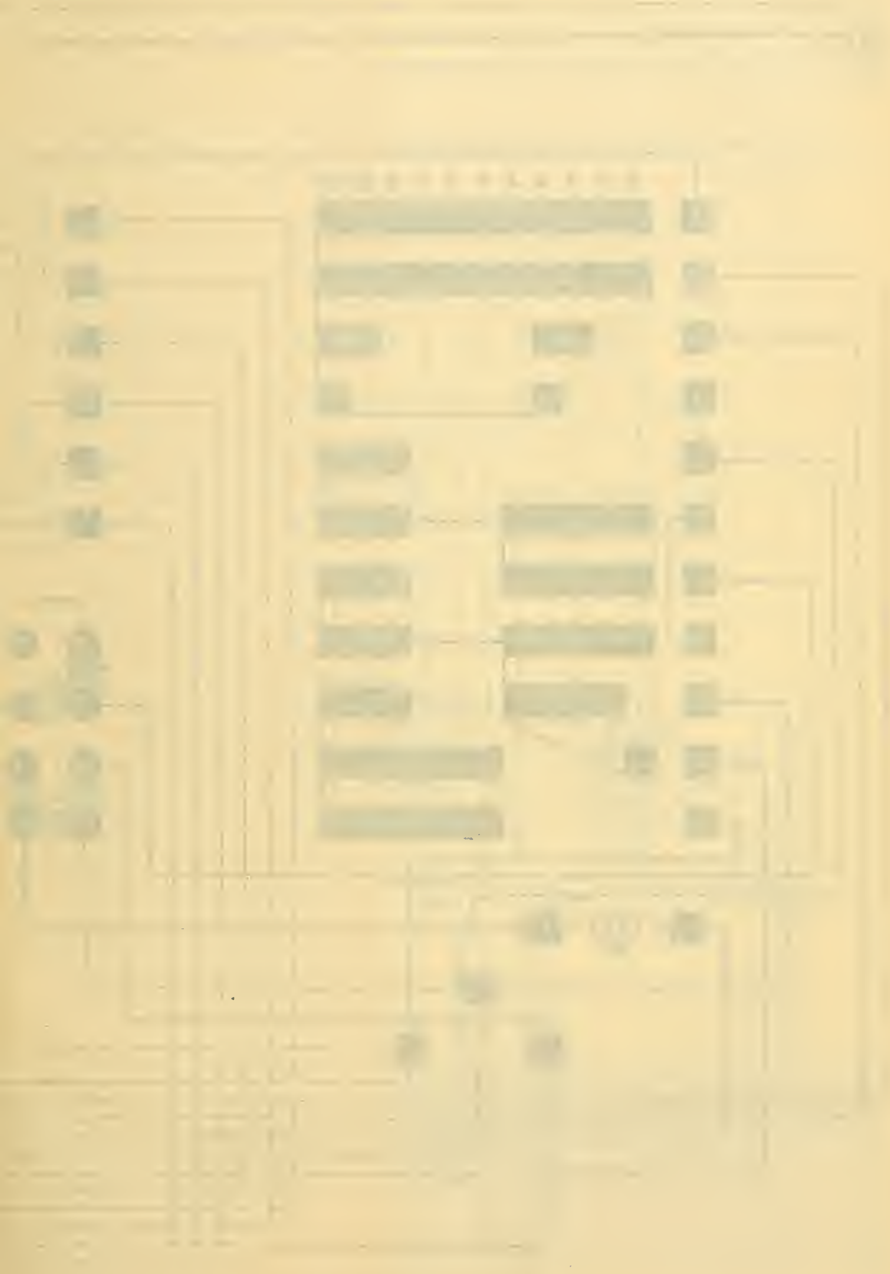
FIG. 37.

54. Car-Wiring Diagram.—Fig. 38 is a car-wiring diagram of the Westinghouse 28A controller. K, K are the two hood switches; W, the trolley wheel; and FB, the fuse box; the lightning arrester is not shown; D is the reverse switch; L_1, the No. 1 motor cut-out switch; and L_2, the cut-out switch for the No. 2 motor; $R_4 R_5$ is the small one-part starting coil; and $R_1 R_2 R_3$ the large two-part starting coil; M is the magnetic blow-out coil that goes around the base of the finger board, as shown in Fig. 31; M_1 is the No. 1 motor or the motor through which the current first passes in its passage from the trolley wire to the ground; M_2 is the No. 2 motor or the motor next to the rail or ground.

55. Notes on Car-Wiring Diagram.—In Fig. 38, the cut-out plugs are shown turned so that both motors are cut in, and the dotted lines at L_1 and L_2 are not supposed to represent connections in this position of the cut-out plugs. The path of the current from the trolley wire to the ground on the first notch is $W–K–K–FB–T–a–a_1–R_1$, along the car wire, as indicated by the arrowhead, to the positive end of the large starting coil at R_1, through the large starting coil and out at R_3, along the R_3 car wire to post R_3 at the left, through the blow-out coil $M–X–13–14–9–F_1+\,–F_1+\,–F_1+$, through the No. 1 motor field, $F_1-\,–F_1-\,–F_1-\,–A_1+\,–A_1+\,–A_1+$, through the No. 1 motor armature, $A_1-\,–A_1-\,–15–16$, to post R_4; thence on the R_4 car wire to the R_4 post on the positive end of the small starting coil, through this coil and out at R_5 to finger $R_5–c_4–c_2–8–6–b_2–b_3–7–17–18–12–11–F_2+\,–F_2+\,–F_2+$, through the No. 2 motor field, out at $F_2-\,–F_2-\,–F_2-\,–A_2-\,–A_2-\,–A_2-$, through the No. 2 motor armature, out at A_2+, directly to the ground wire at G.

56. The two dotted circles in the diagram of the No. 2 motor indicate the fact that the motor is turned end for end, so that its commutator cannot be seen from the same end as can that of the No. 1 motor, whose commutator outline is, therefore, indicated by the full-line circles.

In Fig. 38, only one controller is shown connected up. To connect up the other one, it is only necessary to connect the broken-ended wires in the lower right-hand corner of the



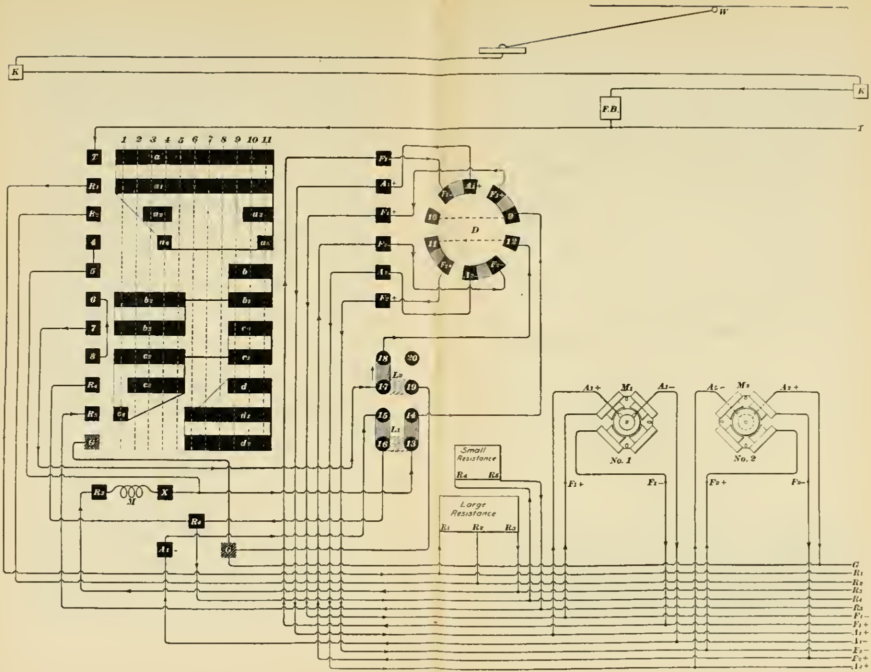

W
K
K
F.B.
T
1 2 3 4 5 6 7 8 9 10 11
T
R1
R2
4
5
6
7
8
R4
R5
G
a
a1
a2
a3
a4
a5
b
b1
b2
b3
c1
c2
c3
c4
c5
d
d1
d2
F1-
A1+
F1+
F2-
A2
F2+
D
9
10
11
12
18
20
17
19
15
14
16
13
L2
L1
R3
M
X
R6
A1-
G
Small Resistance
R4
R6
Large Resistance
R1
R2
R3
A1+
M1
A1-
F1+
F1-
No. 1
A2-
M2
A2+
F2+
F2-
No. 2
G
R1
R2
R3
R4
R5
F1-
F1+
A1+
A1-
F2-
F2+
A2+

FIG 38

sketch to the posts marked the same as these wires are on their ends.

57. Fig. 39 shows the combinations effected by the 28A controller. The fourth and seventh are the running notches. In this controller it will be noted that the resistance is made up into two parts, one of which, R_1 to R_3, is connected, on the first notch, in circuit ahead of the No. 1 motor, and the other smaller part, R_4 to R_5, is connected between the two motors on the first notch. The controller differs in this respect from the General Electric controllers, where the resistance is all in one place. It makes very little difference where the resistance is put so long as it is included somewhere in series with the motors.

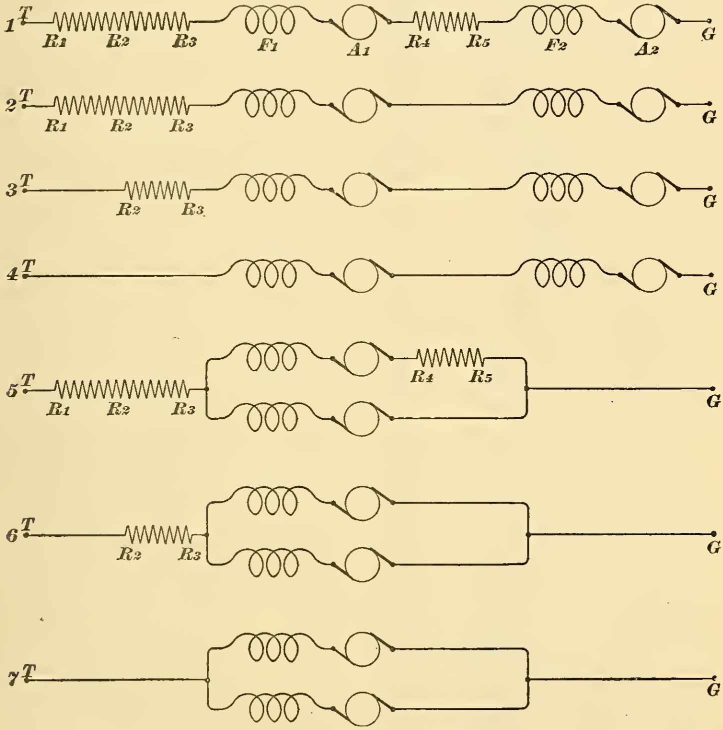


FIG. 39.

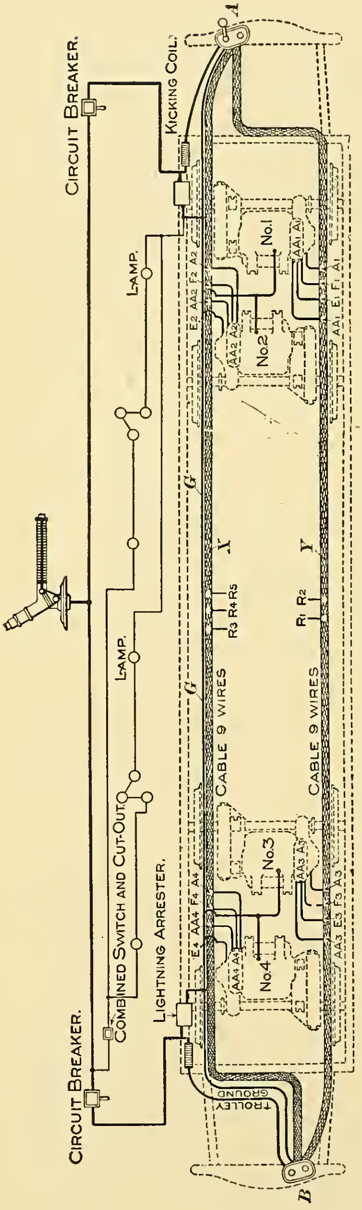


Fig. 40.

FOUR-MOTOR EQUIPMENTS.

58. The general tendency in electric railroading has been towards larger cars and higher speeds. In many cases, the comparatively short single-truck car has given place to the long double-truck car. These long cars may be equipped with either one or two motors on each truck. In some places, maximum-traction trucks, with a single motor on each, are used. In other places, ordinary four-wheeled trucks with a motor mounted on each axle are used. There has been much discussion as to whether four motors of moderate size are as economical as two larger motors. Tests have shown fairly conclusively that the four-motor equipment will use more current than the two-motor equipment under similar conditions; but with four motors, one on each axle, the whole weight of the car rests on the driving wheels, and it has been found that these cars can ascend grades, go through snow, and run on slippery rails, where the two-motor equipment has great difficulty in maintaining its schedule time. This is an important consideration, and four-motor equipments are extensively used notwithstanding the fact that they take more current and are higher in first cost than two-motor equipments. The cost of repairs is also greater with the four-motor equipment.

59. General Arrangement and Method of Control. Fig. 40 shows the general layout of the wiring for a car equipped with four motors and General Electric K12 controllers. The motors, *1*, *2*, *3*, and *4*, are mounted back to back, two on each truck. The resistance coils are mounted under the middle of the car and are connected to the taps R_1, R_2, R_3, R_4, R_5. The two controllers *A* and *B*, the resistance coils, and the motors are connected together by wires run in the cables *X* and *Y*. Each of these cables is made up of nine-stranded rubber-covered wires pulled into canvas hose. *G G* is the ground wire, which is not run in the hose. This ground wire is connected to the frames of all four motors, as shown in the figure. One end of the fields of motors Nos. 2 and 4 is also tapped to the ground wire.

60. The usual method for controlling a four-motor equipment is to connect the motors in pairs in parallel and then to treat the two pairs as if they were single motors, operating them by the series-parallel method, as with a regular two-motor equipment. This will be understood by referring to Fig. 41, which shows the various combinations effected by the K12 controller.

If the student will refer to the description of the K11 controller, he will see that the combinations given in Fig. 41 are practically the same as for the K11, except that here we have four motors in two pairs instead of the two single motors. No. 1 motor is connected in parallel with No. 3, and No. 2 with No. 4, so that a motor on one truck is connected in parallel with a motor on the other (see Fig. 40).

61. The K12 Controller.—The K12 controller used for the operation of four motors is similar in general appearance

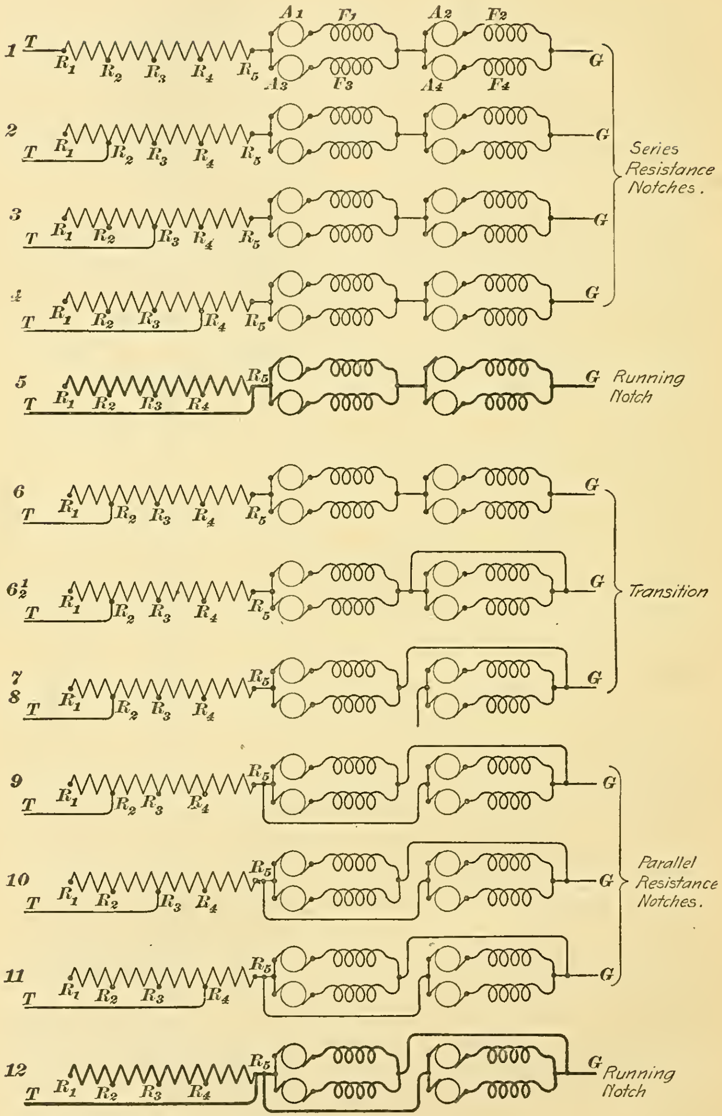

A1
F1
A2
F2
1
T
R1
R2
R3
R4
R5
A3
F3
A4
F4
G
2
3
4
Series
Resistance
Notches.
5
Running
Notch
6
6½
Transition
7
8
9
10
Parallel
Resistance
Notches.
11
12
Running
Notch

FIG. 41.

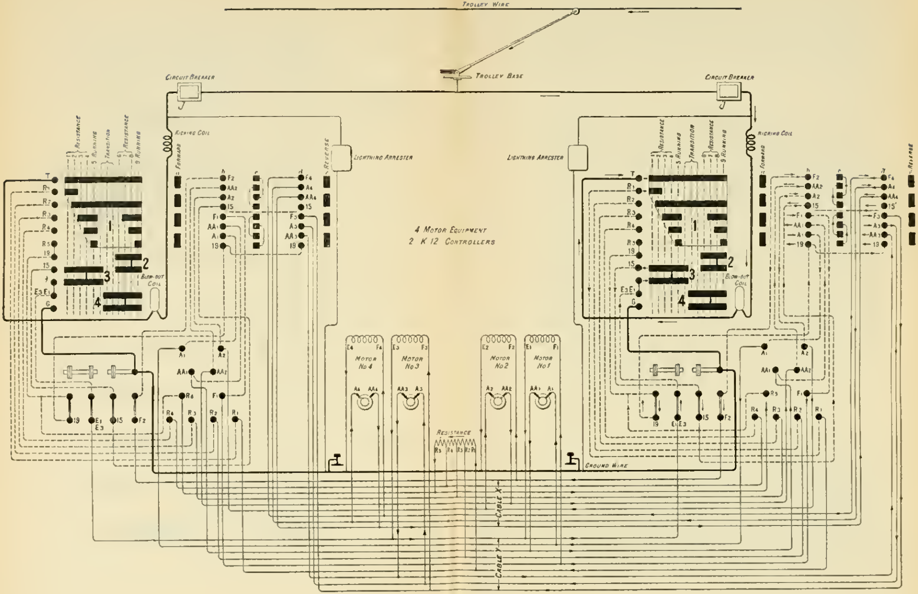

Trolley Wire
Trolley Base
Circuit Breaker
Circuit Breaker
Kicking Coil
Kicking Coil
Lightning Arrester
Lightning Arrester
Resistance
Running
Transition
Resistance
Running
Forward
Reverse
Forward
Reverse
Blow-out Coil
Blow-out Coil
4 Motor Equipment
2 K 12 Controllers
Motor No 4
Motor No 3
Motor No 2
Motor No 1
Resistance
Ground Wire
Cable X
Cable Y
T
R1
R2
R3
R4
R5
19
15
E3 E1
G
F2
AA2
A2
15
F1
AA1
A1
19
F4
A4
AA4
F3
A3
AA3
1
2
3
4
E4
F4
E3
F3
E2
F2
E1
F1
A4
AA4
AA3
A3
A2
AA2
AA1
A1
R5
R4
R3
R2
R1
E1
E3
F2

FIG. 42.

to the other type K controllers made by the General Electric Company. Its contact fingers and drum contacts are heavier than the K2 or K10, because the four motors require a large current. The use of the four motors requires some modifications in the construction of the reversing switch, but otherwise the controller is very similar to those just considered.

62. Fig. 42 is a wiring diagram for a car equipped with four motors and two K12 controllers. The power drum is very similar to that of the K10 controller, but a double row of contact fingers is provided on the reverse switch. When the car runs ahead, the reverse-switch fingers b are in contact with plates a and fingers d are in contact with c. When the car runs back, fingers b make contact with c and d with e, thus reversing the current in all four armatures. The leads E_2 and E_4 from the No. 2 and No. 4 motor fields are permanently connected to the ground wire. The main trolley wire connects to the blow-out coil, as shown. The student by this time should be able to trace out the path of the current on the various notches for himself, so that it will not be necessary to give the various combinations. The path of the current on the first notch is indicated by the arrows and is as follows, starting from post T at the power drum: $T-R_1-R_1-R_1$, through all resistance, $-R_5-R_5-19-19-$

$$\left\{\begin{array}{c} 19-A_1-A_1-A_1-A\,A_1-A\,A_1-A\,A_1-F_1-F_1-F_1-E_1-E_1-E_1-3 \\ 19'-A_3-A_3-A\,A_3-A\,A_3-F_3-F_3-E_3-E_3-E_1-3 \end{array}\right\}-$$

$$15-15-\left\{\begin{array}{c} 15-A_2-A_2-A_2-A\,A_2-A\,A_2-A\,A_2-F_2-F_2-F_2-E_2 \\ 15'-A_4-A_4-A\,A_4-A\,A_4-F_4-F_4-E_4 \end{array}\right\}-$$

Ground.

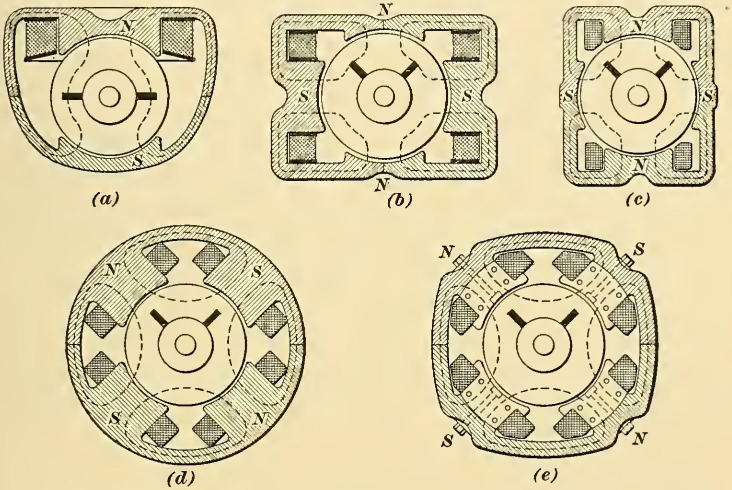
63. The other combinations are indicated by Fig. 41, and may be easily traced out on the diagram. When the cut-out switches are operated, the motors are cut out in pairs. For example, if something goes wrong with the No. 1 motor and the cut-out switch is thrown up, motors No. 1 and No. 3 are cut out. Four-motor cars require a large current; hence, care must be taken to see that the main wiring has plenty carrying capacity. The student will also notice in Figs. 40 and 42 that the two circuit-breakers are connected in parallel, whereas the hood switches shown on the other diagrams are connected in series. This is the usual practice when circuit-breakers are used. The breaker on the front end is in while the car is running and the one on the rear end is left out, so that only one breaker is in use at the same time. If both breakers were in series, they would both trip in case a short circuit occurred, and the tripping of the one on the rear platform, in close proximity to the passengers standing there, would be undesirable; besides, it might not be convenient to reset the breaker on the back end, because the conductor would very likely be engaged in collecting fares. For these reasons, the breakers are connected in parallel instead of in series.

STREET-RAILWAY MOTORS.

64. A street-railway motor has to meet several conditions not imposed on motors that are used for stationary work. Its design is limited to a large extent by the space in which it is to be placed. It must go wholly beneath the car floor, and its width is limited by the gauge of the track. It must be dust-proof and waterproof, because it may have to run through all kinds of dirt and water. It must be arranged so that it can be readily suspended from the car axle. A railway motor must be substantial in every particular, because it is called on to stand harder usage than almost any other kind of electrical machinery.

As mentioned before, nearly all motors used for railway work are operated by direct current at 500 volts. The fields are connected in series with the armature, because the series-wound motor is capable of giving a strong starting effort and also gives a wide range of speed under varying loads. Moreover, the series-field coils, being wound with a few turns of coarse wire, are substantial and comparatively easy to repair. Alternating-current motors will, no doubt, be used much more in the future for railway work than heretofore, but at present their application to this line of work is limited. The general construction of a street-railway motor is the same as that of any other direct-current motor. In other words, it must have a field magnet, armature, commutator brushes, etc. The field frame is made so that it will enclose the motor as much as possible. The earlier motors were only partly enclosed, but the later types are wholly enclosed. Access is allowed to the commutator and brushes by means of a hinged or removable lid.

65. Fig. 43 illustrates sections of some of the styles of field that have been used on street-railway motors. (*a*) is the style used on the old Thomson-Houston W. P. 50 (waterproof) motor. It is a two-pole field with a single magnetizing coil. (*b*) is the field used on the old Edison No. 14. It is a four-pole field with two field coils. (*c*) is the General Electric 800 (G. E. 800) motor field. It is similar to the Edison No. 14, but is turned up the other way. (*d*) shows the four-pole magnet frame introduced about 1891 by the Westinghouse Company in their No. 3 motor. It has four



(*a*) (*b*) (*c*)
(*d*) (*e*)

FIG. 43.

poles set on the diagonal and each pole is provided with a field coil. This style of field has been used on nearly all street-car motors since, and practically all motors are now of the four-pole type, with their pole pieces set on the diagonal. Of course, the frame has been modified so as to enclose the motor and modifications have been made in the construction of the pole pieces. Cast steel has replaced cast iron for the magnet frame, allowing it to be made much lighter and stronger, but the fact remains that the frame and general construction of the Westinghouse No. 3 motor contain the main features of the motors as constructed at present. (*e*) shows a field about as used on a modern motor. Here the frame is of cast steel and can be made comparatively light. The pole pieces, instead of being cast with the frame, are built up of sheet-iron stampings and are bolted to the frame. This laminated pole construction reduces heating in the pole pieces and also tends to keep down sparking at the commutator.

Railway-motor armatures are of the slotted type. The coils are wound on forms and are then placed in slots on the core. In the earlier slotted armatures, a large number of slots were used, generally anywhere from 87 to 105. This was necessary because if the slots were made coarse, it was found that they caused the magnetism in the pole pieces to vary to such an extent that the solid poles would heat considerably. By laminating the poles, it has been found possible to reduce the number of slots to about one-third the number formerly used, thus making the slots very much larger, cheapening the cost of production, and making the motor operate better generally.

66. Speed Reduction.—It has not been found practicable or economical to drive ordinary street cars by means of direct-connected motors, i. e., by means of motors the armatures of which drive the axle directly without the use of any gearing. Such motors may be used where the motors are of large capacity, as on some electric locomotives, but in practically all cases geared motors are used. If the motor drives the axle directly, the speed of the armature must, of course, be the same as that of the axle. This means that the motors must be designed for very low speed, and hence are heavy and bulky for their output. The heavy weight on the axles is hard on the track and the track joints are soon pounded out. For these reasons, the general practice is to use geared motors, so that the armature may be allowed to run four or five times as fast as the axle, thus keeping the size and weight of the motor for a given output within reasonable bounds. Direct-connected motors have been brought out and tried in connection with ordinary trolley cars, but they have not proved a success. They may, however, be used more in the future for the heaviest kinds of electric traction.

67. Speed Reduction.—When electric railways were first put into operation the motors ran at a much higher speed than those built at present, and it was necessary to transmit the power to the axle through an intermediate shaft. The small gear or pinion on the end of the armature meshed with a large gear on one end of the intermediate shaft, and a small gear on the other end of the intermediate shaft meshed with the axle gear. Motors of this kind were known as **double-reduction** motors, because of the double reduction in speed between the armature and the axle.

As the design of railway motors was improved, it was found possible to make efficient motors that would run slow enough to admit gearing direct to the axle, thus dispensing with the intermediate shaft. This is the kind of motor now almost universally used, and is known as the **single-reduction** type, because there is but one reduction in speed between the armature and the car axle. The ratio of the number of teeth in the gear to the number of teeth in the pinion gives the amount by which the speed of the axle is reduced as compared with the speed of the armature.

For example, suppose an axle gear has 65 teeth and the armature pinion 14 teeth; then the armature runs

$\frac{65}{14}$ = 4.64 times as fast as the axle, because the armature has to make 4.64 turns for every turn that the axle makes. The **gear ratio** is, therefore, 4.64 : 1, the axle gear having 4.64 times as many teeth as the pinion. Various gear ratios are used in practice, depending on the size of the motors and on the speed at which the cars are to be run. If the cars are to run at a slow speed, the number of teeth in the axle gear will be large compared with the number in the pinion, and *vice versa*. The most common values of the gear reduction lie between 4 and 5. It will not be necessary to go into details regarding double-reduction motors, as they are no longer used. The number of different types and sizes of single-reduction motors in use is very large, and it would be an endless task to take up all of them. We will, however, take up two or three representative types, and the student will note that there is comparatively little difference between them so far as their general design is concerned. Motors are, of course, being improved all the time, but they have now reached a point where the changes are more in the line of improvements in details rather than radical changes in design.

GENERAL ELECTRIC MOTORS.

68. The General Electric Company have made a great variety of motors, some of the more common of which are the G. E. 800, G. E. 1,000, G. E. 1,200, G. E. 52, G. E. 54, etc. The numbers 800, 1,000, 1,200, etc. were given to these motors to denote the number of pounds drawbar pull that the motor could exert when taking full-load current and when mounted on 33-inch wheels. This method of rating the motors has now been dropped, and the machines are designated by arbitrary numbers, such as 52, 54, etc. The field used on the G. E. 800 and G. E. 1,200 is of the type shown at (*c*), Fig. 43. The G. E. 1,000 has four poles arranged on the diagonal, as shown in Fig. 43 (*e*). The poles are, however, not laminated, but consist of steel castings bolted to the frame, and the armature is therefore provided with a large number of small slots. The G. E. 1,000, G. E. 52, and G. E. 54 are much the same in general appearance. We will select the G. E. 52 motor for illustration.

G. E. 52 MOTOR.

69. Motor Frame.—Fig. 44 shows the general appearance of the G. E. 52 motor. The general shape of the field frame is hexagonal; it is made in halves, which are held together by bolts. The two arms *b*, *b* extending from the back of the motor receive one-half the axle bearing, which is in the shape of a split bushing. The axle-bearing caps *c*, *c* are provided with grease boxes, and the grease or oil is fed on the axle by means of pieces of felt from underneath as well as from the grease cups on top. The bolts *d*, *d* hold the pole pieces and field coils in place. The removable cover *e* allows access to the commutator and brush holders. The lower armature-bearing caps *f* are separate from the lower half field *A*, and by leaving these caps in position, the

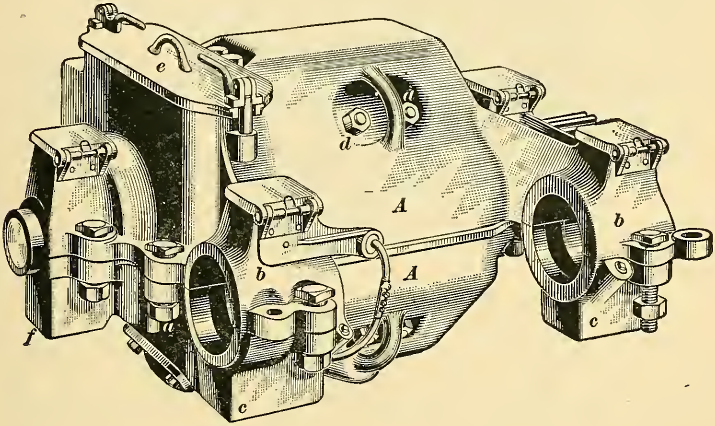


FIG. 44.

lower half field *A* may be swung down, leaving the armature in the upper half, as shown in Fig. 45. The lower half field is here swung down and the two lower pole pieces are exposed for repair or inspection. By removing the bearing caps, the armature can be lowered with the field, thus leaving the upper field coils and pole pieces exposed, as shown in Fig. 46. Most modern motors are constructed in this way, because it is a great convenience in inspecting and repairing the motors.

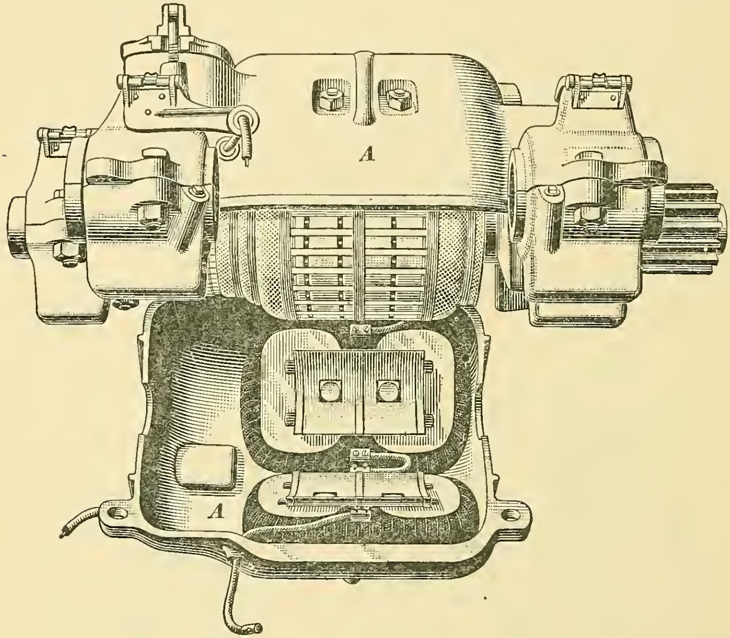


FIG. 45.

70. Capacity of G. E. 52 Motor.—The G. E. 52 motor has an output of 27 horsepower. This means that it will develop 27 horsepower continuously for 1 hour, and at the end of the hour the temperature of the windings will not be more than 75° C. above the temperature of the surrounding air. The motor is intended for ordinary street-railway work and is not recommended for the heavier kinds of traffic.

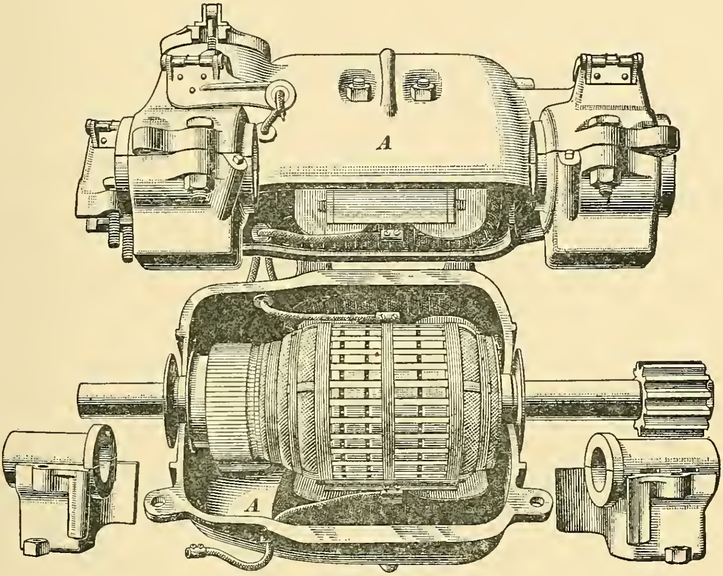


FIG. 46.

71. Pole Pieces.—The motor has four poles provided with flanged pole pieces that are laminated; the flanges serve to hold the field coils in place, and the laminations not only do away with a great deal of heat in the pole piece, but from the way in which they are built up, they produce a magnetic field that does away with much of the sparking at the brushes. The pole pieces are made of iron plates shaped

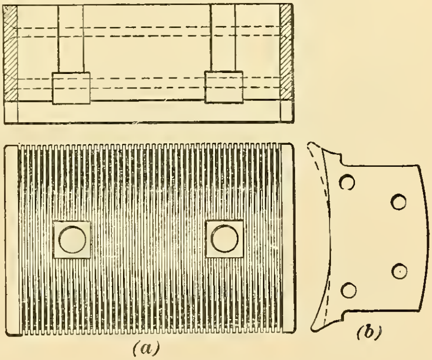


FIG. 47.

something like the full-line part of Fig. 47 (*b*). The pole pieces are built up of these plates, every other one of which is turned end for end. The result of this manner of construction is shown in Fig. 47 (*a*), where, along the horizontal center part of the pole piece, the plates are close together, but on the horns only half of the plates come out on each side. This plate construction, to a great degree, does away with sparking at the brushes, because the thinning out of the metal on the horns of the pole pieces produces what is called a *shaded field* or *fringe*. This means that the pole-piece horns are so made that the lines of force are distributed in such a way that they gradually become thinner and thinner at the proper rate and in the right place. This shaded field provides a fringe that reverses the current in the coil passing under the brush, and hence brings about the change in the direction of the current with but little sparking.

72. Field Coils.—The field coils are wound on forms, and while the asbestos-covered wire is being wound it is treated with a mixture of chalk and japan and afterwards baked. The coils are heavily insulated with tape and insulating varnish and are given a glazed surface that will readily turn off water and prevent moisture getting in.

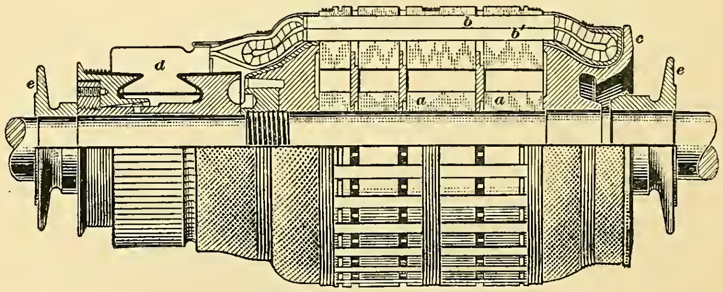


FIG. 48.

73. Armature.—Fig. 48 shows a half section of the G. E. 52 armature, and its construction is typical of many of the railway-motor armatures now in use. The core is provided with 29 slots. One side of 6 coils goes into each slot, so that there are 87 coils altogether, and the commutator has 87 bars. The coils are bunched in groups of three, and one side of one bunch goes into the bottom of a slot, one side of another into the top of the same slot. In Fig. 48, *a a* is the laminated armature core and *b*, *b'* the upper and lower halves of two different coils lying in the same slot. The ends of the coils, where they project from the core, are supported and protected by the end shield *c*. The leads from the coils are connected to the commutator bars *d*, which are mounted as shown. The flanges *e*, *e* are for preventing grease and oil working their way into the armature. The bearings are so arranged that any oil getting on *e*, *e* drops through an opening to the street.

74. Brush Holders.—Railway-motor brush holders are fixed permanently at the neutral point and are not arranged so that they can be shifted, as is the case with many other direct-current machines. The reason for this is twofold. In the first place, the motor has to run in either direction, and in the second place, the variations in load are so sudden that any brush-shifting arrangement is out of the question. The brushes are, however, mounted so that they can be moved radially towards the center of the commutator as the latter wears away.

Fig. 49 shows the brush holders and brush-holder yoke of the G. E. 52 motor. The yoke *a*, which is made of well-seasoned hard wood treated with insulating material, is bolted to the upper field frame by means of bolts *b*, *b*. The brush holders *h*, *h* are bolted to brass slides on *a* by means of bolts *c*, *c*. All railway motors use carbon brushes, and in this case, two brushes 2¼ in. × 1¼ in. × ½ in. are used in each

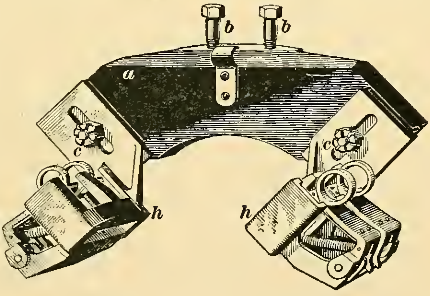


FIG. 49.

holder. The brushes are radial, i. e., they point towards the center of the commutator, so as to work equally well for either direction of rotation of the armature.

75. Gears.—The standard gear for the G. E. 52 motor has 67 teeth and the pinion 14 teeth, making a gear reduction of $\frac{67}{14} = 4.78$ to 1. Fig. 50 shows the motor mounted on the axle complete with its gear case shown at the left. All modern motors are provided with gear cases that are kept partly filled with soft grease or oil. This greatly prolongs the life of the gears by keeping them well lubricated and by shutting out dirt and gritty material. The holes *a*, *a* receive the bolts for attaching the suspension bar that is used to hold the motor in place.

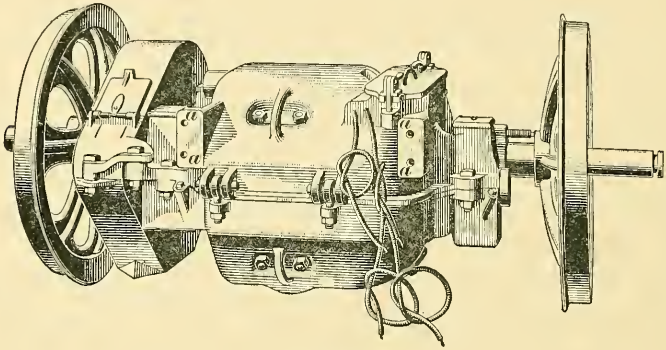


FIG. 50.

76. Nose Suspension.—Fig. 51 shows another view of the suspension. This is the ordinary **nose suspension** so widely used. *P* is the small gear or pinion, *G* the axle gear, and *W* the car wheels. The back of the motor is supported by the axle and the front is held up by means of a crossbar or yoke bolted to the front of the motor and resting on springs supported by the side frames of the truck. The arms cast on the motor frame hold the gears at the proper distance from center to center, while the outer part of the motor is free to rise up and down. The motor is thus supported flexibly, and there is not nearly as much pounding action as if it were mounted directly on the axle. The weight of the G. E. 52 motor without axle gear and case is 1,460 pounds.

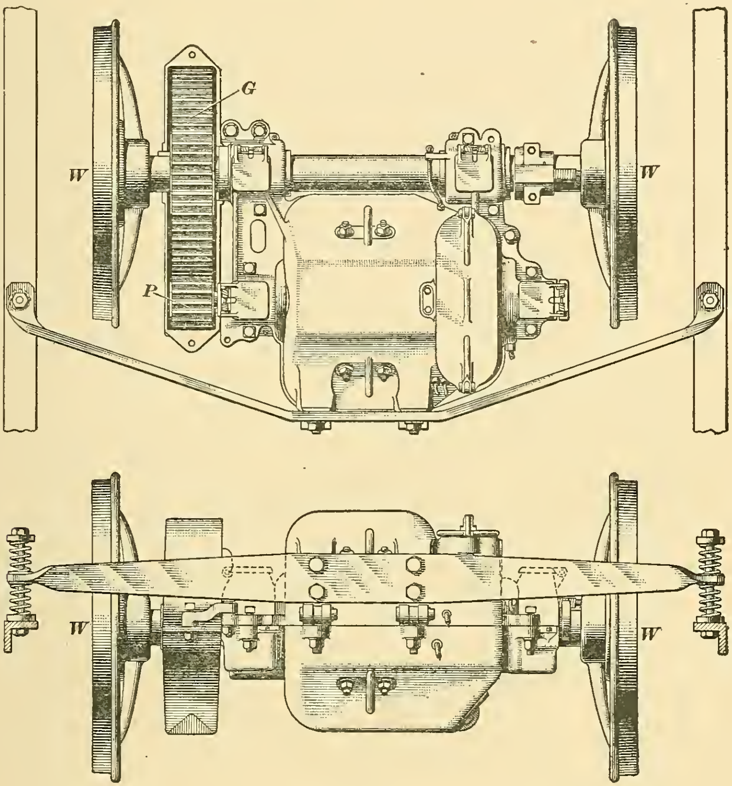


FIG. 51.

WESTINGHOUSE NO. 56 MOTOR.

77. The Westinghouse No. 56 motor is intended for the heavier kinds of street-railway work. It is intended for interurban or cross-country traffic or for any service where heavy cars are operated at high speed. Fig. 52 shows the motor closed, and it will be seen that its construction is much the same as the motor previously described. A, A' are the top and lower halves of the field frame, which is made of mild cast steel. The lid C may be thrown back to get at the commutator and brushes. The armature leads are shown at a, a' and the field leads at f, f'. Post g is used for making the connection to the ground. The lug l is used to hang the motor when the nose suspension is used. Sometimes the motor is supported by side bars or by a cradle that passes through the rectangular openings r at

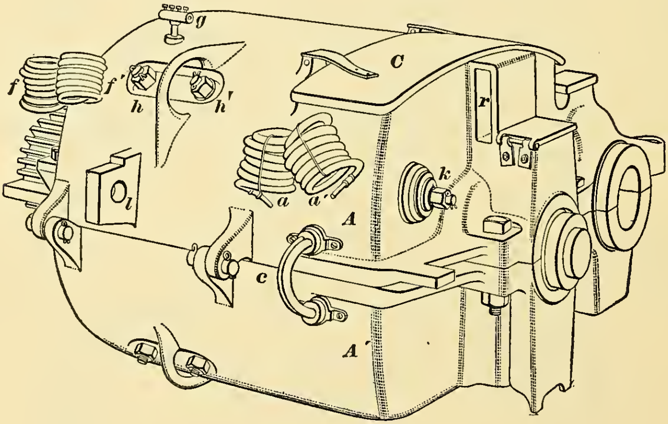


Fig. 52.

each end of the motor. The wires shown at c connect the top and bottom field coils together. The pole pieces are laminated and held in position by the bolts h, h', and the armature bearings are so arranged that the armature may be either swung down with the lower half or retained in the upper half. The bearings are provided with grease cups on the top and wick lubrication below. In this motor the brush holders are bolted to the frame, but, of course, are thoroughly insulated from it. One of the bolts for attaching a holder is shown at k. The total weight of the motor, not including the axle gear and gear case, is 2,680 pounds.

78. Cradle Suspension.—Fig. 53 shows the **cradle suspension** as applied to the Westinghouse No. 56 motor. The front of the cradle *A A* is supported at *C* by the cross-beam *D*, which is supported by the side frames of the truck. The back end of the cradle is supported by springs *S*, *S'*, which bear on lugs cast on the same arm that carries the axle bearing. The cradle passes through the lugs on the ends of the motor, and the use of the springs insures a flexible suspension.

79. Capacity of No. 56 Motor.—Different makers have different ways of rating the capacity of their motors. Some rate them at the power they are capable of developing for a run of one hour without their temperature rising more than 75° C. above that of the surrounding air. Of course, the current taken by a motor in actual service is very variable, and the voltage at the terminals of the motor is also variable. For example, when the two motors are in series, each motor will get about 250 volts if the line voltage is 500. When the car is coasting or standing still, the voltage applied to the motors is zero. The average voltage applied to a motor throughout the day will not likely be more than 250 or 300 volts, and the No. 56 motor will carry a load of 50 amperes *continuously* at a pressure of 300 volts with a rise in temperature of 75° C. Of course, much larger currents than this can be carried for short intervals, as, for example, when a car is starting up and getting under headway. The motor can carry a current of 100 amperes for over an hour without increasing the temperature over 100° C., provided it starts at 25° C. With 100 amperes, a tractive effort of over 1,600 pounds would be exerted with the motor mounted on 33-inch wheels. The continuous output of a railway motor, like any other electric motor, is limited by the heating. Railway motors are generally worked at a fairly high temperature, because they must be enclosed to such an extent that free ventilation is difficult.

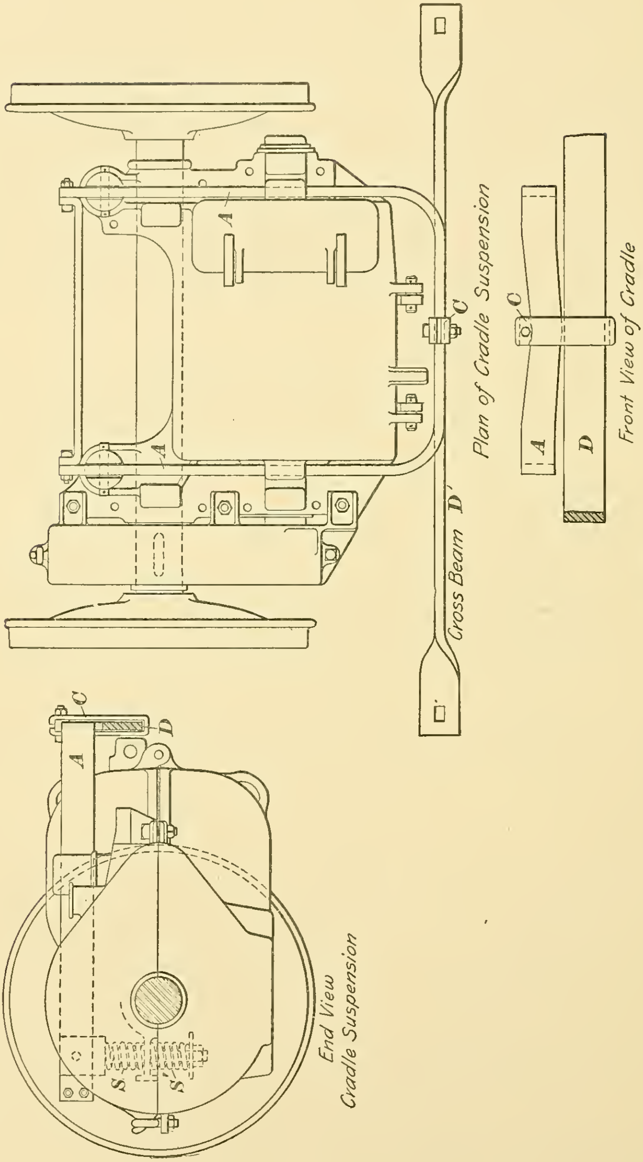

A
A
C
Cross Beam
D'
Plan of Cradle Suspension
C
A
D
Front View of Cradle
C
A
D
S
S'
End View
Cradle Suspension

FIG. 53.

RAILWAY-MOTOR ARMATURE CONNECTIONS.

80. There are so many different styles of railway-motor armatures that it will not be possible to take up the methods of connecting the different kinds in detail. The following will, however, give some general directions relating to these connections. These all relate to four-pole machines and the coils span over about one-quarter of the armature. They also refer to drum-wound armatures exclusively, as ring armatures are not used to any extent on modern railway motors. In former times, the cores were separately insulated and the wire was wound on from a reel; these armatures were known as *hand-wound armatures.* At present, the core insulation is confined to insulating disks on the ends, a strip of insulation in the bottom of each slot, and pieces of insulation, in some cases, on the sides of the slot. The coils are wound first on coil machines and then insulated and pressed to a shape to fit the slot. By using form-wound coils, much less skill is required to repair or rewind armatures. The first step was to have a slot for each coil; the next step was to bunch two coils together in one insulating casing or armor, so that the armature core had but one-half as many slots as there were coils. This practice left two empty half slots that had to be filled with a dummy coil (i. e., a coil whose ends were insulated instead of going into the commutator), so the scheme of using 2 coils in a case was abandoned in favor of grouping 3 coils in a case, so that a core need have but one-third as many slots as coils.

81. Modern street-railway armatures are of the series-connected type; that is, although a machine may have four poles, the armature is so connected that it has but two paths through it, and therefore requires but two brush holders. On an enclosed motor, four brush holders would be out of the question, because the bottom ones could not be inspected and it would be almost impossible to replace a brush if the motor were hot. Another point to bear in mind is that some motors have their pole pieces on the diagonal, while others have them on the vertical and horizontal, with the result that on the former type, the brushes are set on the commutator at points opposite the centers of the pole pieces instead of being set at points midway between them corresponding to the position of the neutral line. This is necessary from the fact that if the brushes were set at the neutral line, one would be on top and the other would be down on one side, where it would be hard to get at.

82. Connections for a 99-Coil Armature.—Fig. 54 shows an armature having 99 coils and slots, its pole pieces being horizontal. The coil for this armature would have one short lead and one long one, and would be of such a width that one side could drop into slot *1* and the other side into slot *26*; the short lead would then go straight down to the commutator bar immediately in line with it and the long lead would go to the bar as nearly diametrically opposite as possible. This would be bar *50*. The next coil would drop into slots *2* and *27* and its leads would go to bars *2* and *51*. This is a rule that holds good on any armature having 99 slots and 99 coils where the four poles are on

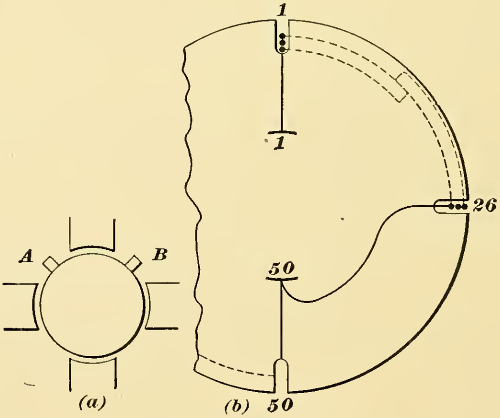


FIG. 54.

the horizontal and vertical, as, for example, on the G. E. 800 or 1,200 motors. To make it hold good on armatures having 99 coils, 99 bars, but only 33 slots, it is only necessary to count off as if each coil had its own slot or as if there were no slots at all. For instance, suppose there are only 33 slots; then, one side of coils *1*, *2*, and *3* will be in slot *1*; *4*, *5*, and *6* in slot *2*; *7*, *8*, and *9* in slot *3*; and so on, so that the other sides of coils *1*, *2*, and *3*, which formerly fell into slots *26*, *27*, and *28*, when there was a slot for each coil, must now drop into slot *9*; the other sides of coils *4*, *5*, and *6* in slot *10*; and so on. The short lead of coil *1* goes to bar *1* and the long lead to bar *50*, as before. After one coil is installed, the others follow the same course.

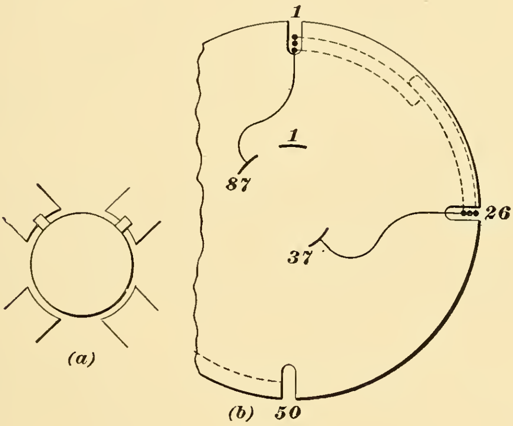


FIG. 55.

Fig. 55 shows the connections for an armature having 99 slots and 99 coils, with the pole pieces on the diagonal. It will be noticed that in both cases, the brushes fall in the same place. In Fig. 55, however, the lead out of slot *1*, instead of going to bar *1*, directly opposite, goes to bar *87*, obtained by counting to the left 14 bars, including bar *1*; 99 is not divisible by 8, so that this is as nearly one-eighth a circumference as it is possible to get. Since the lead coming out of slot *1* is shifted $\frac{1}{8} \times 99$ bars to the left, so must the lead out of slot *26* be shifted the same amount, so that instead of going into bar *50*, it goes into bar *37*, which is 14 bars to the left, counting bar *50*. In practice, the two bars are located as follows: The coil is dropped into slots *1* and *26*; begin with bar *1*, opposite coil *1*, and count 14 to the left, including *1*; this fixes one end of the coil in bar *87*; then, including bar *87*, count 50 bars to the right, which fixes the other end of the coil in bar *37*. After one coil is in, the others are easily placed. This scheme of bringing the connections around one-eighth a circumference to the left is called *giving the connections a lead.*[*] It is nothing but a mechanical trick for bringing the brushes into the right place, and is used on all street-railway motor armatures whose pole pieces are on the diagonal. In Fig. 54, one lead is longer than the other, so that they are readily distinguished by their length; in Fig. 55, the leads are about the same length, so that to distinguish them, it is the practice to slip a piece of black hose on one, the other being white. Fig. 55 can be followed in assembling and connecting any armature that has 99 coils and either 99 slots or 33 slots, if the pole pieces are on the diagonal.

83. Connections for a 95-Coil Armature.—Figs. 56 and 57 give the general scheme for winding and connecting any armature having 95 slots and 95 coils for vertical and diagonal pole pieces, respectively. In Fig. 56, the coils drop into slots *1* and *25*, as before, but the lead out of slot *1* goes straight down to bar *1* and the other end of the coil in slot *25* goes half way around the commutator to bar *48*. In Fig. 57, one side of the coil goes into slot *1* and the other side into slot *25*; the bar in front of slot *1* is bar *1*. Including bar *1*, count off 13 to the left; this fixes the lead coming out of slot *1* in bar *84*. Including bar *84*, count off 49 bars to the

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[*] The term "lead" as applied here should not be confused with the term "lead" as applied to a wire or terminal. In connection with armatures, dynamos, etc., the term "lead" (pronounced "leed") is commonly used to denote a terminal wire—such as the terminal of an armature coil—a wire running from a dynamo to the switchboard, etc.

right; this brings us to bar *37*, which takes the other end of the coil coming out of slot *25*.

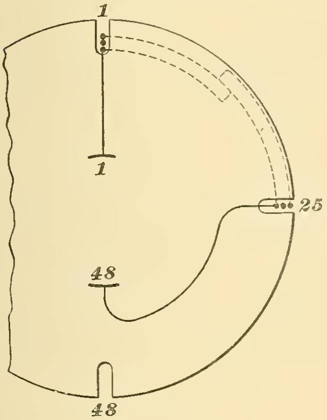


FIG. 56.

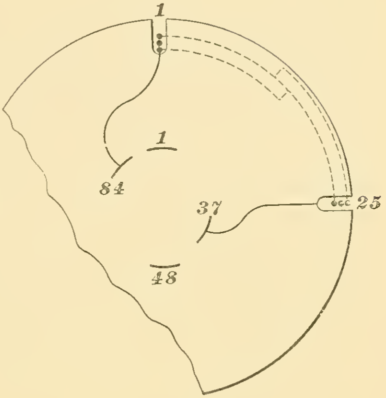


FIG. 57.

84. Connections for a 93-Coil Armature.—Figs. 58 and 59 show the scheme for winding and connecting any armature having 93 coils and bars and 93 or 31 slots for vertical and diagonal pole pieces, respectively. In both cases, the coil drops into slots *1* and *24*. In the first case, the lead out of slot *1* goes straight down to bar *1* and the lead from

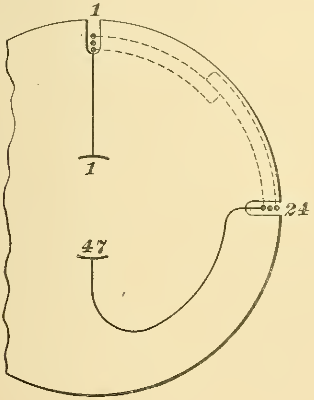


FIG. 58.

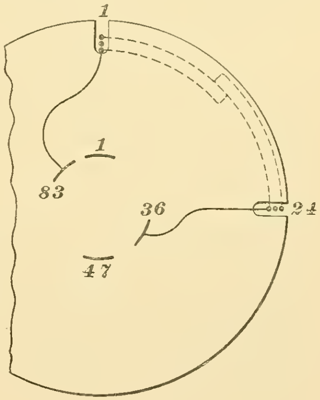


FIG. 59.

the same coil in slot *24* goes half way around and connects to bar *47*. In the second case, the lead from slot *1* goes into bar *83*, which is found by counting off 12 to the left of bar *1* and including it; the other end of the same coil in slot *24* connects to bar *36*, obtained either by going half way around the commutator from bar *83* to the right or by counting off a throw of 12 back from bar *47*.

85. Connections for a 105-Coil Armature.—Figs. 60 and 61 show, respectively, the vertical and diagonal methods of winding and connecting an armature having 105 slots, bars, and coils. In both cases, the first coil drops into slots *1* and *27*. In the first case, the lead out of slot *1* goes straight down to bar *1* and the other end of the same coil coming out of slot *27* goes half way around to bar *53*. In the second case, count off a throw of 14 bars to the left from and including bar *1*, which gives bar *93*, the bar for the lead out of slot *1*. To get the bar for the lead of the same coil out of slot *27*, count off 53 to the right from bar *93*, which gives *40*.

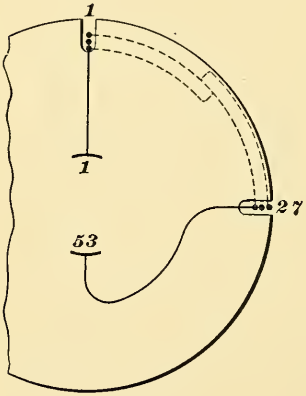


FIG. 60.

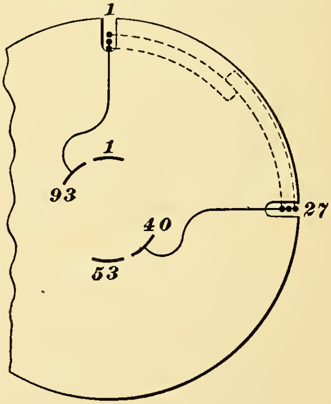


FIG. 61.

86. Connections for Armature With 93 Coils and 47 Slots.—Fig. 62 shows the scheme for connecting up for diagonal pole pieces an armature having 93 bars and coils but only 47 slots; the single coils are done up into cells or cases, two coils to a cell; there are 47 of these cells, so there will be 1 coil (2 ends) more than there are places in the commutator. This extra coil might just as well be left out, so far as doing any work is concerned, for its ends are taped up so that they cannot come in contact with any other parts of the winding, but it is put in to preserve the mechanical balance of the armature. As shown in the figure, the coil drops into slots *1* and *13*. To connect the armature, pick out any coil and find both ends of it with a magneto or lamp circuit. Standing at the commutator end, call the end on the left *1*. With a straightedge, find the bar immediately in front of it; call this bar *1*, and count off 13 to the left; this fixes the left-hand lead at bar *82*. The other lead goes into the bar half way around the commutator or bar *35* to the right.

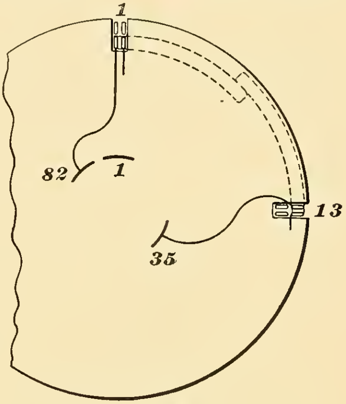


FIG. 62.

87. In all these winding diagrams, the student will note that one side of the coil occupies the bottom of a slot, while the other side of the same coil is in the top of a slot about one-fourth of the distance around the armature. By arranging the coils in this way, the crossings at the ends of the armature are easily disposed of, and in nearly all modern railway motors this arrangement is adopted.

There are many different styles of armature windings for railway motors, and for this reason it has been thought best to take up general principles that may be applied to any of them rather than particular cases. Practically all railway motors use windings that are, in general, similar to those described, although the exact grouping of the coils in the slots may be somewhat different.

RAILWAY-MOTOR FIELD CONNECTIONS.

88. One of the most common sources of trouble in connection with street-railway motors is wrongly placed or connected field coils. Few have any idea of the great amount of trouble a wrongly connected field coil may cause. Its effect is felt long after the trouble has been found and removed. A wrongly connected field not only injures itself, but it injures the other field coils and the armature. The armature probably heats to such an extent that it throws solder and the fields gradually bake inside, with the result that the car is soon turned in for blowing fuses. The chances are that before the trouble is discovered and removed, there may be two or three grounded brush holders, armatures, or fields, due to the current jumping across to the frame of the motor, because the weak fields in the first place cause poor commutation, and in the second place reduce the counter E. M. F. and allow more current to flow than the brushes can stand. It is safe to say that one-half of the trouble on cars turned in for blowing fuses can be traced directly or indirectly to defects in the field coils.

89. General Remarks on Field Coils.—Fig. 63 shows a section through the middle of a four-pole motor having top and bottom field coils. The halves of the shell come apart along the line *A B*. In Fig. 63, the two coils are connected correctly, and the general path of the lines of force forms the curved four-sided figure at the center. In Fig. 64, the two field coils have been left off to simplify the drawing,

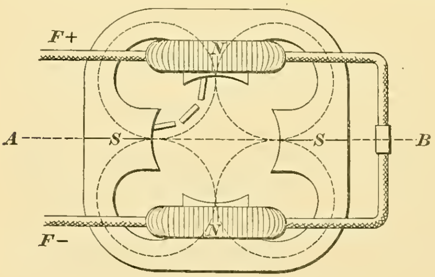


FIG. 63.

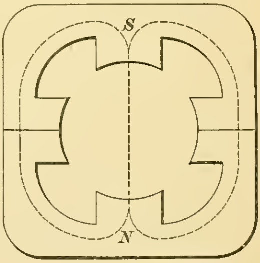


FIG. 64.

but the figure is supposed to be the same as Fig. 63, except that the two coils are connected incorrectly, so that opposite poles are of opposite polarity and the side pole pieces cease to be poles at all. The lines of force pass across the armature core just as they would in a regular two-pole machine, with the result that the neutral point falls midway between the brushes, which are in an active part of the field, and therefore spark a great deal even when the car is run with the two motors in series.

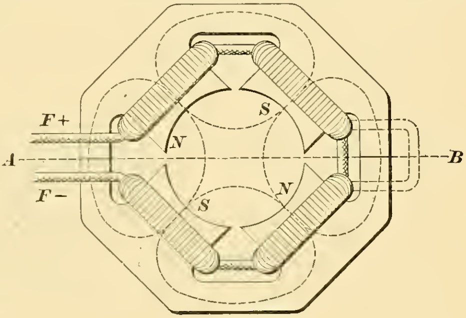


FIG. 65.

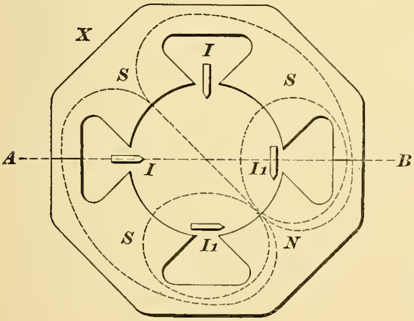


FIG. 66.

Fig. 65 shows a section through a four-pole motor that has a coil on each of its poles. The coils are so connected that the pole pieces alternate in polarity. Fig. 66 is the same as Fig. 65, but the field coils are not shown. The top left-hand field coil is supposed to be connected incorrectly, with the result that the motor has three south poles and only one north pole, and the lines of force are very much twisted out of their path. However, it will be noticed that two sides of the four-sided figure made by the path of the lines of force can still be seen. Part of the armature is, therefore, effective, and, as a matter of fact, if one coil out of four is wrongly connected, the car will continue to start and run on the faulty motor, but the brushes will spark badly. One wrong field coil out of four amounts to about the same thing as lifting off the top half of the motor and running the armature on the field coils in the lower half. The armature would run, but there would be great consumption of current.

90. Test for Field Connections.—If there is any doubt as to whether a set of field coils is connected properly or not, the matter can be decided by a very simple test with a piece of soft-iron rod about 3 or 4 inches long. It is well known that if a piece of iron is placed near a magnet of any kind, it will, if free to move round a center, take up a position parallel to the general direction of the lines of force that run through the place where it rests. If the person making the polarity test is inexperienced, it is a safe plan to take the armature out of the motor, because when a current is sent through the field coils and the pole pieces become magnetized, they induce poles of the opposite polarity in the armature core opposite them, so that unless great care is taken, the tester will not always be certain whether he is getting the effect of the pole piece or that of the induced pole in the armature core.

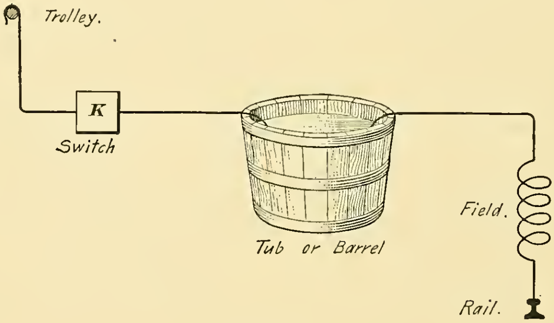


Fig. 67.

Procure a piece of $\frac{1}{4}$-inch iron rod and point it on one end, so that the two ends may be distinguished by feeling them. Next send a current through the fields; this can be done by using a tub or barrel of water as a resistance, connected as shown in Fig. 67. The wires going into the tub have each a fish-plate or an old bearing attached to their submerged ends. The current can be varied by varying the distance between these pieces of metal. Sometimes it is necessary to drop a handful of common salt into the water, in order to bring down its resistance and pass a current strong enough for the test. As soon as the current is adjusted (it should not be more than the full-load current of the motor), reach into the motor and rest the blunt end of the piece of iron on the horn of one of the pole pieces and let the sharp end point towards the pole piece next to it; then pass the piece of iron on over towards the pole piece that it points at, as shown in Fig. 63. The piece of iron is held loosely at the center between the thumb and forefinger, so that it is free between certain limits to turn and follow the path of the lines of force. If the iron rod in its passage from one pole to the other tends to remain in the same general direction in which it was started, i. e., starts from one pole on its blunt end and reaches the other pole on its sharp end, showing no tendency to turn or straighten up, the path of the lines of force is correct.

Fig. 68 shows the action of the piece of iron if one of the coils is connected incorrectly. If the motor has only two coils, as shown in Fig. 63, the lines of force, when one of the coils is incorrectly connected, will take the path straight across, shown by the dotted line in Fig. 64, and the piece of iron, instead of being willing to go in the most natural way from one pole to the one next to it, will try to follow the direction shown at I_1, I_1 in Fig. 68. Of course, if the motor has only two coils, matters can be set right by reversing either of them. It does not matter whether the motor has two coils or four coils; if they are all connected properly, the path of the lines of force from one pole to another will be regular, and the piece of iron will persevere in taking up between each pair of adjacent poles the position shown at I, I, Fig. 68.

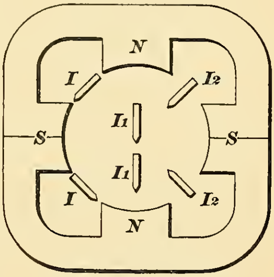


FIG. 68.

Now, suppose the motor to be of the four-coil, four-pole type, such as shown in Fig. 65, and suppose the left-hand top field coil to be wrongly connected, so that the path of the lines of force becomes that shown by the dotted lines in Fig. 66. In this case, the test iron will rest in positions I, I on both sides of the faulty coil, because the general direction of the lines of force is at right angles to what it should be. Between the right-hand bottom coil and the two adjacent coils, the path of the lines is correct and the test iron takes up the correct position, as shown at I_1 and I_1. If, then, one of the four coils on any four-coil motor is wrongly connected, the action of the test iron will be irregular on both sides of that coil. Further than this, the pole piece coming out of the faulty coil will be weaker than any other pole piece in the motor; also, the removed corners of neighboring pole pieces will be considerably stronger than the corners adjacent to the faulty pole piece.

91. Field Connecting.—In the practical work of connecting up a set of field coils, one does not care whether the coil is connected so that it makes the pole piece a north pole or a south pole; what one must see to is that if any given pole is a north pole, the pole next to it on either side must be a south pole, and *vice versa.* Now, whether a pole will be north or south depends on the direction in which the current flows around it. This in turn depends on how the coil is wound, how the leads are brought out after it is wound, and, lastly, on how the coil is connected when it is in the motor. As we have to do only with the completed coil in the motor, we will assume that all the coils are wound alike and that in every case the inside and outside ends of the winding go to the same lugs or leads, respectively. If the current enters a coil by way of the inside end, the coil will give the pole piece one polarity, and if it enters at the outside end of a similarly placed coil, the polarity of that pole piece would be reversed. In order to make adjacent pole pieces have opposite polarity, the current must enter the coil of one at its inside end and the coil of the other at its outside end.

Fig. 69 shows four coils laid out in the same order in which they would go into a motor and connected so that the current flows through all of them in the same direction. Fig. 70 shows them connected as they should be. In Fig. 69, it will be noticed that each of the four coils has one long lead and one short one; so that if connected as shown in Fig. 69, the coils will all have the same polarity, because in each case the current goes into the coil by way

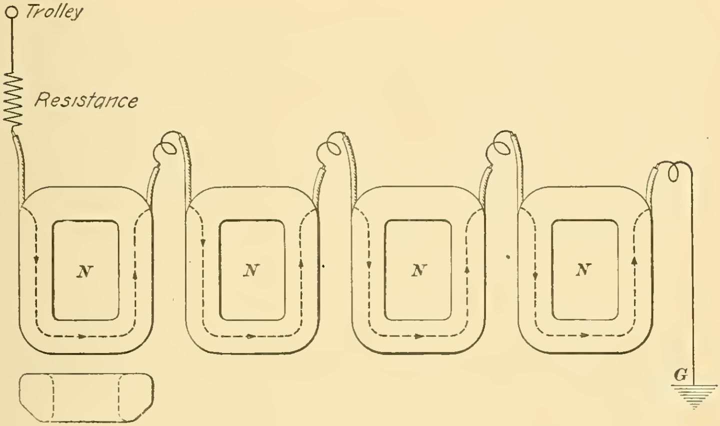


FIG. 69.

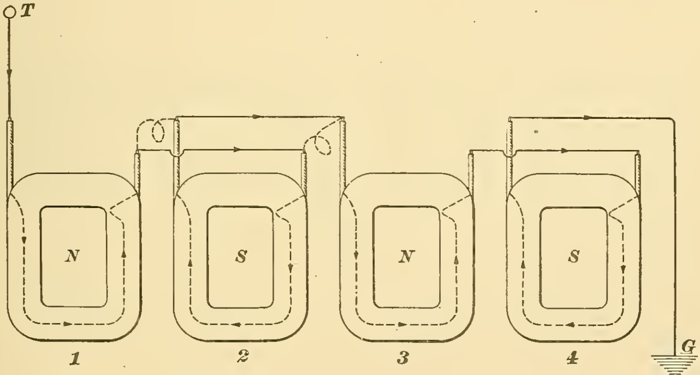
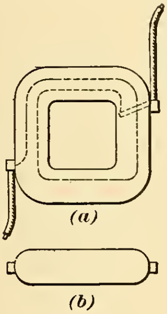


FIG. 70.

of the long lead and comes out by way of the short one, circulating through all the coils in a counter-clockwise direction.

There are two points that must be especially noted about the four field coils and their connections in Fig. 70; one is that the difference in the length of the leads enables one to tell readily which are the like ends of several coils. The next point to note is that the like ends of coils that are next to each other join together; a short lead always connects to a short lead and a long lead to a long lead. One more point to be noticed is that, after all the internal motor-field connections are made, the two field leads that are left unconnected to go to the field car wires should be alike; in Fig. 70, two long leads are left open, so that the connections must be correct. In Fig. 69, one long lead and one short lead are left open, so that the connections are not correct. It is, however, possible to get the coils connected improperly and still have two like ends left open; Fig. 70 shows one way in which this might be done if the second coil were connected as indicated by the dotted lines instead of by the full lines. The connections should be carefully made and well taped up, because they are in very close quarters and are liable to chafe.

92. Coils With Leads on Opposite Ends.—Fig. 71 shows a type of coil that is very easily placed incorrectly. Fig. 72 is the same style of coil except that it has leads instead of lugs. It does not make any difference which way the coil is turned; it looks just the same. To add to the possibility of confusion, the coil has the same shape on the bottom as on the top, as shown in Fig. 71 (*b*), so that it is an easy matter to get the coil into the motor top side down. The effect of getting such a coil in end for end, or top side down, can be seen by the aid of Fig. 72. In this figure, *T T* is supposed to be the wire that takes the current to the coil; if this wire is connected to the coil as it stands in the figure, the current goes into the coil by way of the *F*+ lead, which we will call the *inside end;* if the coil be now turned over so that the *a* side comes where the *b* side is, and *vice versa*, the *F*— lead is brought nearest the wire *T T*, and if it is connected to it, the current enters the coil by way of the outside end and reverses its polarity.


(a)

(b)

FIG. 71.

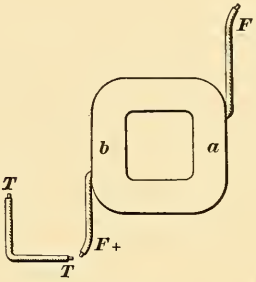


FIG. 72.

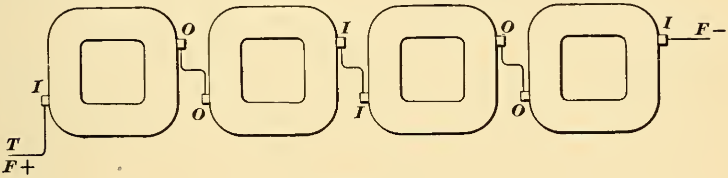


FIG. 73.

Fig. 73 shows how such a set of coils appear if they are connected correctly, and Fig. 74 shows the effect of having one coil in top side down. Observe that in Fig. 73 the *I*'s connect to *I*'s and the *O*'s to *O*'s; also, that every other coil is turned end for end; this is done in order to bring together those lugs that connect together, thus avoiding a long connecting wire, which would have to be cleated up to keep it

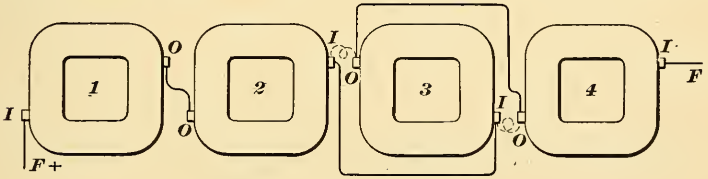


FIG. 74.

away from the armature. If coil *3* were connected as indicated by the dotted lines in Fig. 74, the polarity of the coil would be reversed.

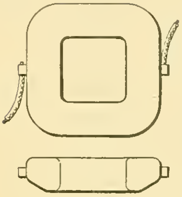


FIG. 75.

Fig. 75 shows a type of coil with the lugs on the side and midway between the two ends. This coil is convex on the bottom and cannot be put in top side down. As the lugs are midway between the ends of the coil, it is an easy matter to get the coil in end for end. The correct connections for coils of this kind are shown in Fig. 76. The connection between coils is short and is not very apt to give trouble from getting loose.

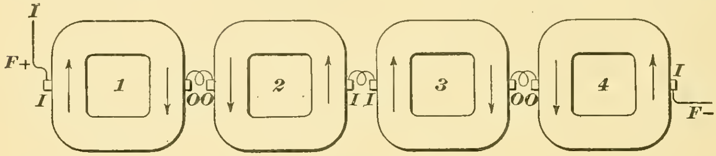


FIG. 76.

ELECTRIC RAILWAYS.

(PART 6.)

CAR APPLIANCES.

1. Trunk Wiring.—Fig. 1 indicates the trunk wiring of an ordinary car and shows those devices, outside of the motors and controllers, that are necessary for the operation of the car. The appliances used for heating and lighting are not indicated. The trolley wheel *b* is held in a *harp* that is mounted on one end of the trolley pole *c*. The other end

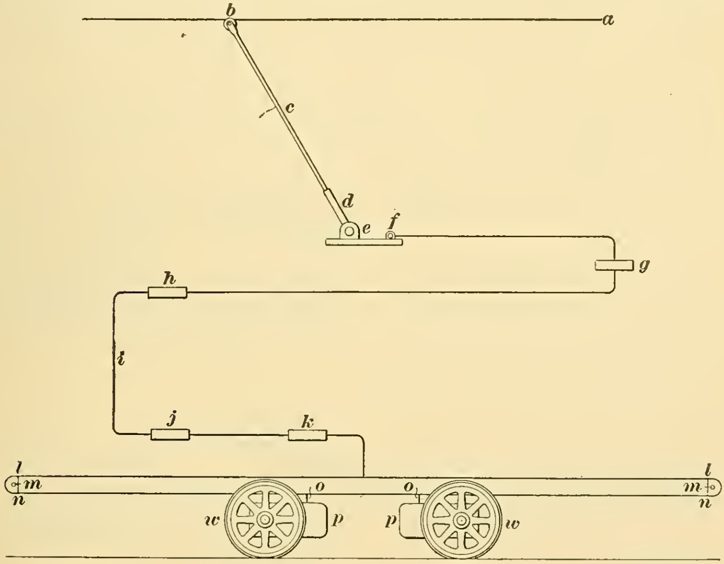


FIG. 1.

of the pole fits into the *socket d* on the *trolley base e*. One end of the trunk wiring attaches to the trolley base at *f* and after passing through the two hood switches *g*, *h* and the fuse box *j*, splices on to the wire *l l* running to the trolley posts in the two controllers. In some cases, the current also passes through the lightning arrester *k*, though usually the arrester is simply tapped on to the main trolley wire.

TROLLEY POLE AND FITTINGS.

2. The Pole. — The *pole* proper, which is from 12 to 15 feet long, is about 1½ inches in diameter at the large end, and holds this diameter for about 2 feet of its length, when it begins to taper and gradually draws down to a diameter of 1 inch. Most poles are steel, hard drawn by a special patented process, and offer great resistance to bending. A slight bend in a pole is generally straightened by using a post with a hole in it as a vise and bending by hand; but severe bends should be taken out by sledging cold. A pole should not be heated to straighten it, as the character of the steel is such that the part heated becomes soft and easily bent. The poles generally used cost from $1.50 to $2.00, according to the length and quality. Fig. 2 gives an idea of the straight and tapered part of a standard pole.

FIG. 2.

3. The Ferrule.—As a rule, each pole is provided with a *ferrule*, which is designed to receive the trolley rope, and which consists of a brass or malleable-iron ring with an eye in it to take one end of the rope. It is secured to the small end of the trolley pole,

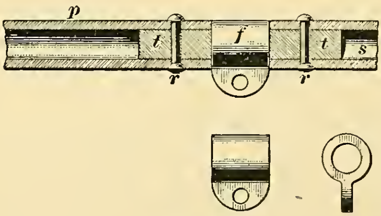


FIG. 3.

as shown in Fig. 3, where *p* is one end of the pole, *f* is the ferrule, and *s* is one end of the harp stem; *t t* is a pin passing into the pole and stem through the ferrule. This pin fits the ferrule loosely, so that the latter may be free to turn when the pole is swung around, but it is forced into the pole and harp stem and is riveted by means of rivets *r*, *r*. A ferrule is not used on all roads, its place being taken by an eye cast in a projection on the harp itself, as shown at *e*, in Fig. 4. In either case, the eyehole should be well rounded out to avoid cutting the rope, a thing that happens very often and causes much inconvenience. Fig. 4 also shows the manner of attaching the harp directly to the pole. In this figure, *b* is the harp; *p*, the end of the pole; and *t*, *t*, the rivets by which the two are fastened to the connecting pin.

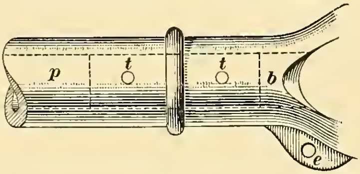


FIG. 4.

4. The **harp** is the name given to the fork that holds the trolley wheel and its axle; it also holds two contact springs *s*, *s*, Fig. 5. In this figure, *b* is the harp proper; *a*, the axle; *s*, *s*, the two springs on either side of the harp; and *c*, *c*, two cotter pins that pass through two holes drilled into the ends of the axle and serve to keep the axle in place. It has been the custom to make trolley harps of brass, but malleable iron is fast replacing it, because it is cheaper and stronger and offers less temptation to thieves. The main points that govern the selection of a harp are narrowness and smoothness; all edges should be nicely rounded off

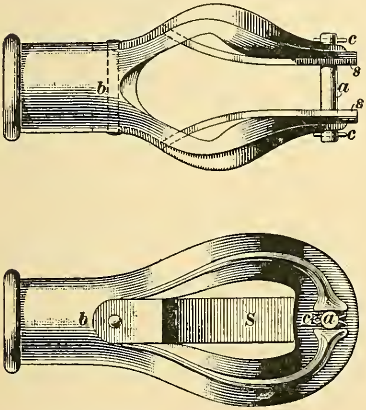


FIG. 5.

to avoid catching in the line work when the trolley wheel flies off the wire. The selection of a good harp means a great saving in poles, ropes, and overhead work.

5. The Wheel.—The trolley wheel is a device on which much experimenting has been done to determine the best shape of wheel and the best composition of metal consistent with long life of the wheel and trolley wire. Some wheels wear out sooner than others and some are harder on the trolley wire than others. A wheel that is too soft will wear out very soon; on the other hand, a wheel that is too hard or that has a poorly shaped groove will scrape the trolley wire at curves and turnouts. Almost all roads go through a certain amount of experimenting to decide what shape and metal are best adapted to the overhead construction. A good lesson can be learned from a careful observation of worn-out wheels; some wheels wear out most in one place and some in another; the same make and shape of wheel will wear differently on different branches of the same road. If both flanges of the wheel persist in getting sharp, it indicates that the groove is too deep or too narrow, or both. If the groove wears down to one side, the indications are that the pole is in crooked or that the harp is crooked or that the trolley wire is out of center. Too

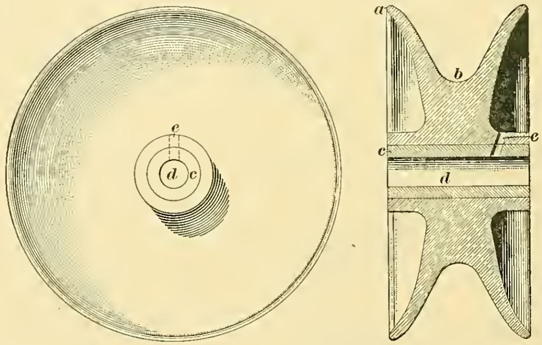


Fig. 6.

much stress cannot be laid on the importance of getting the pole so adjusted that when it is in its normal position, the trolley wire rests on the bottom of the groove and runs parallel to the flanges. Fig. 6 shows a trolley wheel; *a* is the flange; *b*, the groove; *c*, the bushing or bearing; *d*, the hole through which the axle passes; and *e*, the hole for oiling. The bushing, or bearing, is a brass spiral sleeve filled with graphite, and can be forced in or out of a wheel when wear makes it necessary to do so. The bushing is a very particular part of a wheel and should be well made; to keep a bushing in good order, it should be well oiled every fifteen or twenty miles that the car makes; for when it is taken into consideration that a trolley wheel turns around about five thousand times every time that the car runs a mile and that cars make several miles an hour, the importance of a perfect bearing is apparent. On roads that make any pretension to looking after their trolley wheels, a platform is built that overhangs the car roof, so that the wheel may be oiled. Fig. 7 indicates the kind of platform referred to. When oiling a wheel, a piece of waste should be held under it to prevent the excess of oil falling on the roof of the car, where in course of time it makes a mess. When a wheel is allowed to run dry, the hole in the bushing soon wears to an oblong shape, allowing the wheel to vibrate and emit a chattering noise. The same noise may be caused by a wheel having flat spots in the groove. These flat spots may be due to the wheels sliding along for want of oil instead of turning; in other cases, they may be due to some imperfection or they may be due to soft spots in the metal of which the wheel is made. In any case, the wheel should not be run; but should be taken out, and if there is any stock left in it turned down to be used again.

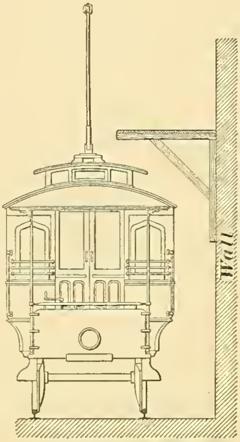


FIG. 7.

TROLLEY STANDS.

6. General Description.—The pole fits into and is held by a device called the **trolley stand,** which gives the pole freedom of motion in two directions: up and down, to enable the pole to adjust itself to stretches of wire varying in height above the ground, and sidewise, so that the pole may be swung around when the direction of motion of the car is changed and also that it can follow the wire freely in going around curves. The trolley stand has two members: the upper member, which holds the pole and is free to turn around the lower member in a horizontal plane, and the lower member, called the base, which is screwed to the board or bridge and acts as a center around which the upper member may turn; this lower member also receives the wire that leads the current from the trolley stand to the controlling devices. The upper member includes the *socket*, the *spring*, and the devices for adjusting the tension on the spring.

7. The Nuttall Trolley Stand.—Figs. 8 and 9 show one form of Nuttall stand. *G* is the socket proper and *f*, *f* two wings forming part of the socket casting provided to receive one end of adjusting rods *e*, *e*, the other ends of which pass through cup castings *d*, *d* to receive adjusting nuts *n*, *n*. On this form of trolley stand the pole may either be rocked over independently or it can be swung around

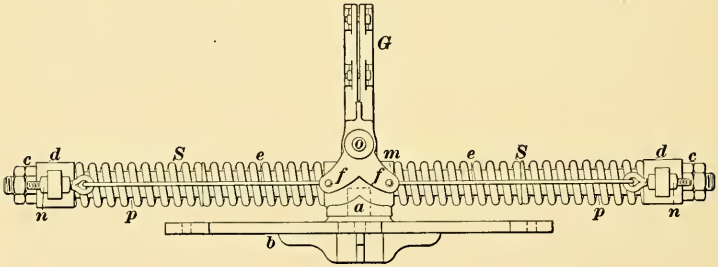


FIG. 8.

with the upper member *m*. Casting *m* also receives the two guide rods *p*, *p*, over which work springs *S*, *S*. When the pole is pulled one way or the other, one pair of tension rods (only one of each pair is shown in the figure) pulls on one compression cup, compresses one of the springs, and produces the desired pressure of the wheel against the trolley wire. To increase the force with which the wheel is pressed against the trolley wire, tighten the nuts *c*, *c*; this will cause some slack in rods *e*, *e*, so that the nuts *n*, *n* also must be tightened. To render springs *S* entirely inactive, remove the nuts *n*, *n* altogether. In the Nuttall trolley, it is possible either to swing the trolley around or to let it stand straight up and rock it over in the opposite direction. All trolley stands do not admit of this, but it is a good feature, because in case a pole is bent, as shown in Fig. 10, rocking the pole over does away with the disadvantages of the bend, whereas

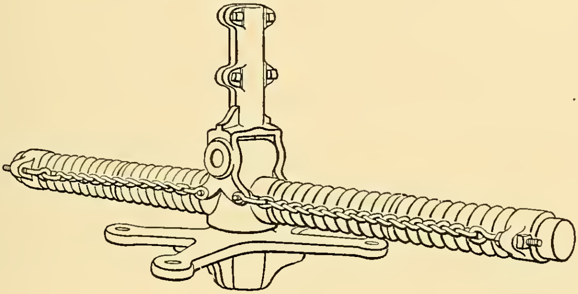


FIG. 9.

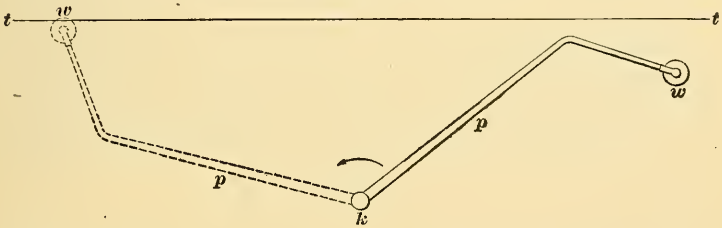


FIG. 10.

swinging the pole will do no good at all. Sometimes, instead of the rods *c*, *e*, chains are used, as shown in Fig. 9.

8. The T. H. Trolley Stand.—Figs. 11 and 12 show a form of trolley stand that was formerly much used. Fig. 12 is a perspective view of the upper member of the stand. On bending the pole to the left, rocker *R* winds up the straps attached to the spring frames and pulls out the battery of springs *S*. To increase the tension, nut *n* must be tightened. It can be seen that with this style of base the trolley pole cannot be rocked over, but must be swung around with the upper member. In Fig. 11 (*b*), a spring *s* may be seen on the main casting *c*. There is a projection on one side of the main casting, and this projection goes into one end of the spring; an iron dog *d* that moves around the same center as the rocker casting *R* has a slight projection that goes into the other end of spring *s*. In case the trolley rope breaks or for any other reason the pole flies up, rib *l* of casting *R* compresses spring *s* and relieves the trolley

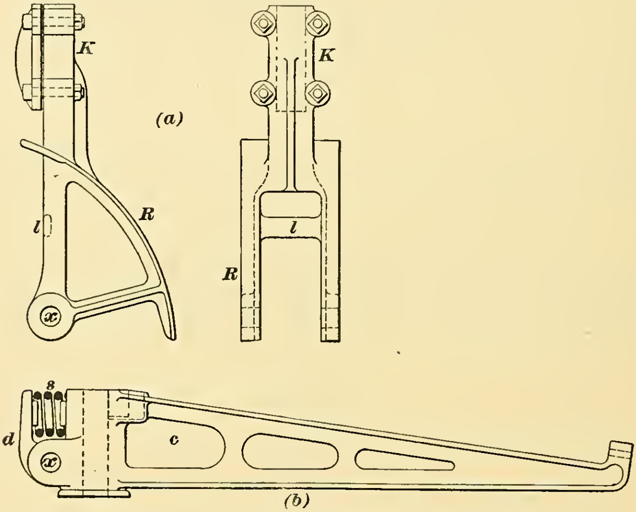


FIG. 11.

stand of the great shock it would otherwise receive. The variety of trolley bases in use is very large, but they all contain about the same essential features.

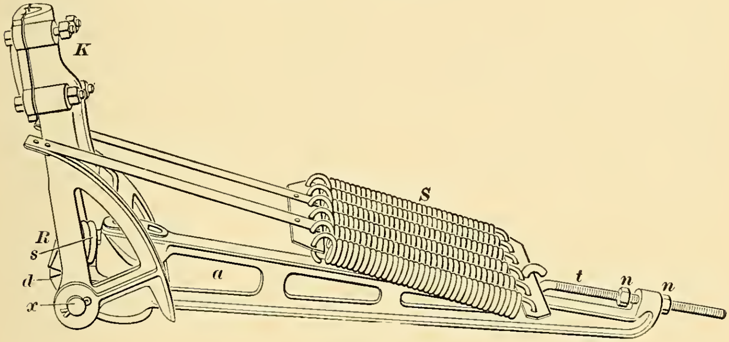


FIG. 12.

9. Pressure Between Wheel and Wire.—The pressure with which the wheel presses against the trolley wire varies from 12 to 20 pounds, according to local conditions and to the speed at which the car is to be run. If the pressure is too light, the pole will be continually jumping off the wire at every kink or turn; if the pressure is too great, it causes an unnecessary wear of the trolley wire, wheel, and axle and also makes it much more difficult to get the wheel back on the wire after it has jumped off. Under ordinary conditions, the pole should make an angle of about 45° with the roof, or deck, of the car, and a pressure of about 15 pounds between the wheel and the wire will usually give good results.

CANOPY SWITCHES.

10. General Description.—The canopy switch, also called the hood switch, bonnet switch, overhead switch, or main-motor switch, is a device that is placed just above the motorman's head on the under side of the bonnet. It is preferably placed a little in front of the motorman's position, so that he can look up and see it without turning his head around. The object of this switch is to provide a certain and simple means of cutting off the main-motor current, in case anything should happen to one of the controllers to make that device useless for throwing off the power. Sometimes a controller becomes grounded or short-circuited, and the consequent flow of current through it is so great that the controller cannot break it; again, sometimes the trouble with the controller or some other device is such that it is very convenient to put the controller on the first or second notch and to start, run, and stop the car by means of the canopy switch. This switch is also used to entirely cut the wiring and all the devices out of communication with the trolley wire when it is desired to inspect or work on any of the controlling devices. A motorman should never try to adjust a controller finger or to replace a broken motor brush without first throwing the canopy switch handle to the off-position.

11. Westinghouse Canopy Switch.—Fig. 13 shows the general appearance of the Westinghouse switch. The switch fixtures are mounted on a wooden base and over the whole is fitted the iron cover provided with four legs, by means of which the switch can be fastened to a wooden baseboard screwed to the under side of the bonnet. The iron cover can be taken off by taking out the three screws *a*, *a*, *a*, exposing the inside to view. These switches are sometimes called upon to break currents from 200 to 300 amperes, and

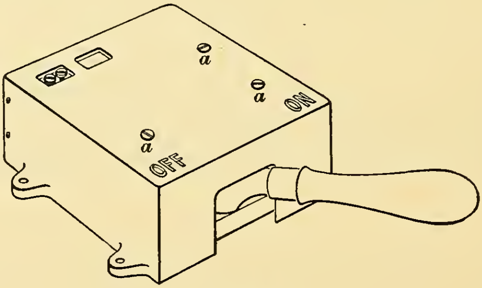


FIG. 13.

some special provision must be made for doing this without too much arcing. In the Westinghouse canopy switch this is accomplished by having the switch blade break the current in two places at once, the two breaks being separated from each other. Figs. 14 and 15 show the construction of the Westinghouse switch blade and the path of the current when the switch is closed. In Fig. 14, *h* is a wooden or rubber handle; *y* is an open-shaped piece of brass terminating in legs *f*, *f* that receive the contact tips *t*, *t*. In Fig. 15, *e*+ is the wire leading into the switch, *e*− the wire leading out of it; *a* and *c* are spring blades set into brass lugs *l*, *l*, separated from each other by the block of insulating material *d*. When the switch is closed, as shown in this figure, contact tips *t*, *t* press into blades *a*, *c*, and the path of the current through the switch is *e*+–*l*–*a*–*b*–*c*–*l*–*e*–.

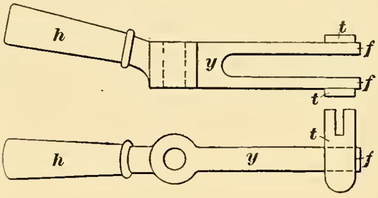


Fig. 14.

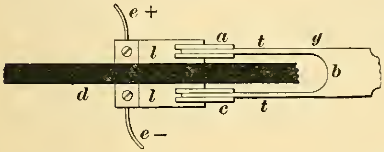


Fig. 15.

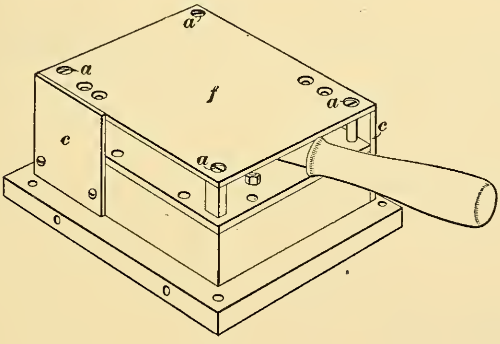


Fig. 16.

12. The General Electric Canopy Switch.—Fig. 16 shows one type of General Electric switch; the interior of this switch is readily exposed to view by removing the four corner screws *a*, *a*, *a*, *a* that secure the fiber top piece *f*. The fiber corner pieces *c*, *c* prevent the flash licking out and disfiguring the car roof, should the switch get a little out of order. This switch is provided with a magnetic blow-out to extinguish the arc; on this account, the switch blade is made of iron, because it carries the magnetism much better than brass or copper. Fig. 17 gives the general idea of how the switch mountings appear when the fiber top *f* is removed. *B* is the switch blade provided with handle *h*, working around a center *p*; *c*, *c* are brass castings provided with holes to receive wires *c*+ and *c*—, and also provided with spring blades *a*, *d*, into which the switch blade presses when the switch is on. When the switch is on, as shown in the figure, the path of the current is *c*+–*c*–*a*–*B*–*d*–*c*–*e*—.

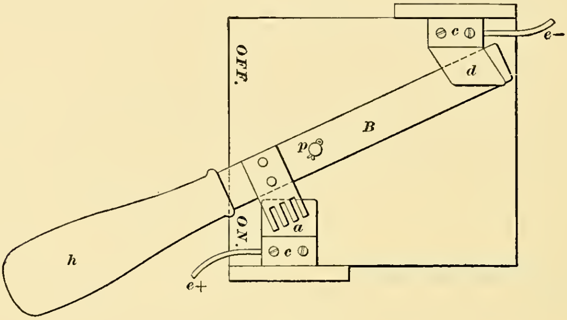


FIG. 17.

13. Fig. 18 illustrates the principle on which the blow-out coil works. *m* and *n* are two pieces of iron; *m* has a handle *h* and is movable around a center; *n* is stationary and has wound upon it a coil of wire that carries the main-motor current; one end of this coil is attached to *n* and the other end of the coil goes to one of

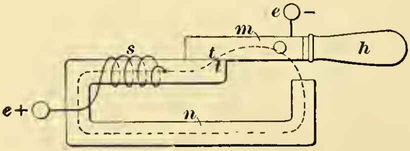


FIG. 18.

the connecting posts $e+$; m is connected to the other binding post $e-$. In the figure, the switch is shown closed; current is therefore passing through it, and the blow-out coil s causes magnetism to pass through the path indicated by the dotted line. As soon as the switch is open, the circuit is broken at t, t and the lines of force flowing across this point break the arc formed there. When the switch is opened, the magnetic and electric circuits are broken in the same place t, t and the magnetic field promptly extinguishes the arc. A switch adapted for use on a 500-volt circuit will not be reliable on a 1,000-volt circuit; nor will switches designed for motors of a certain horsepower work satisfactorily very long on a car equipped with motors of much greater horsepower, because the greater current causes so much more heating that the insulation on the magnetizing, or blow-out, coil gets roasted and becomes carbonized. When this happens, the current, instead of passing around the turns of wire and magnetizing the core, short-circuits through the burned insulation and produces little or no magnetism.

FUSE BOXES.

14. Use of Fuse Box.—It has been seen that the hood switch is a safety device and that it must be operated in case of an emergency by the motorman. The fuse box is also a safety device, but it is automatic in its action. If no fuse box is put on a car, the first time that a ground occurs on a motor or any of its controlling devices, the rush of current is very great and the weakest part of the circuit, that is, the part of least current-carrying capacity, will give way. This weak part may prove to be a loose connection in the car wiring or a bad contact in the controller; but it is more than likely that the weak spot will show up inside a motor, where the damage costs most to repair. The idea of the fuse box is to provide a weak part in the circuit; in case of an abnormal rush of current, the fuse in the fuse box should, therefore, blow before anything else gives way. To make sure that it will do so, the fuse wire is made smaller than any wire found in any of the devices or car wiring that are called on to carry the main current.

SIZE OF FUSE.

15. Factors Determining Dimensions of Fuses.—On a 30-horsepower equipment the armatures are generally wound with about a No. 9 B. & S. wire and the fields with about a No. 4 B. & S. or a No. 5 B. & S. wire, according to the nature of the work that the motor is called on to do. It would appear that in the selection of a fuse wire, it would only be necessary to choose a wire one size smaller than that in the field winding, but for several reasons, this is not so. The fuse wire must be a great deal smaller than the field wire. In the first place, the fuse wire is not embedded in insulation, and in the second place it is not running inside a closed motor, where it can be acted on by other heating influences than the actual current flowing through it. The result of its being outside, in an exposed place, is to give it plenty of air, hence facility to cool, so that for a given current its temperature will not rise as high as that of the wires inside of the motors.

16. Copper Fuses for 30-Horsepower Equipment.—As a result of experience, the copper wire used on a 30-horsepower equipment is about a No. 14 B. & S. A 30-horsepower motor running at full load takes a current of 45 amperes; two motors would, therefore, take a current of 90 amperes at 500 volts and the fuse wire would have to stand this current continuously if the motors always ran at full load. As a matter of fact, a 30-horsepower equipment running under the most usual conditions takes just about one-third of this current, or 30 amperes. Of course, there are times and conditions when the car will take more than 90 amperes, but these do not last long, and if they do, it goes to prove that larger motors are needed for the work, for no 30-horsepower railway motor will bear up under the strain of continual full load.

17. Copper Fuses for 50-Horsepower Equipment.—A 50-horsepower motor under full load at 500 volts calls for a current of about 75 amperes and a fuse wire proportionately larger than that used on a 30-horsepower equipment. The fuse wire should be about a No. 12 B. & S. gauge. The armature of a 50-horsepower street-car motor is wound with about a No. 7 B. & S. copper wire and the field with about a No. 2 B. & S.; so a No. 12 fuse wire gives plenty of margin. In the above it has been assumed that copper wire is to be used in all cases, because there is nothing special about it. It is cheaper than other special fuse wires and is just as reliable.

STYLES OF FUSE BOXES.

18. The Westinghouse Fuse Box.—Fig. 19 shows a perspective view of a Westinghouse car fuse box and Figs. 20 and 21 show how the removable block that takes the fuse wire is constructed.

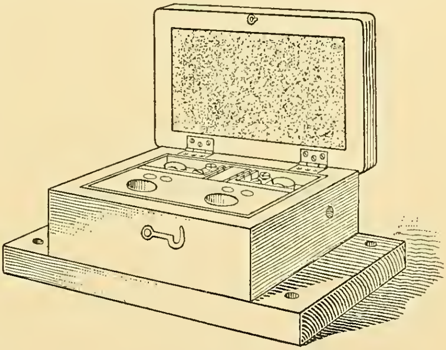


FIG. 19.

Fig. 20 shows the fuse box with the lid open; *a*, *a* are the two castings that receive the two ends of the trunk wiring through holes *d*, *d*; they are provided with switch blades to take the tongues *t*, *t* in Fig. 21. The box and also part *b* of the cover is lined with asbestos, so that the blowing of

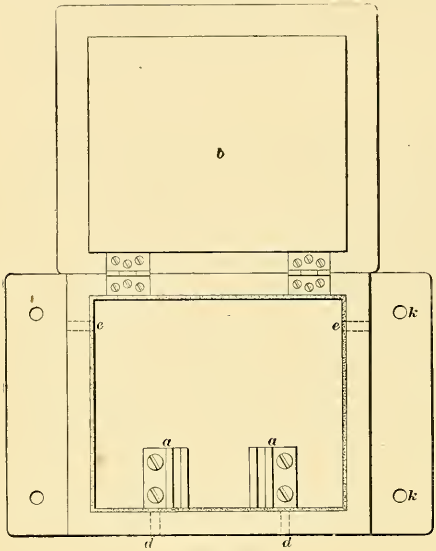


Fig. 20.

the fuse will not set the wooden case on fire. Holes *e*, *e* give the hot air and gases a chance to escape, so that when a fuse blows, the lid of the box may not be blown off. Holes *k* are for the screws that hold the fuse box up against the platform stem under the car.

Fig. 21 shows the removable block to which the fuse wire is attached, as indicated by the dotted line; *b*, *b* are the two thumbscrews by means of which the ends of the fuse wire are secured; *c*, *c* are two finger holes used to withdraw the block when it is necessary to put in a fuse. This fuse box has the great advantage that a fuse can be put in without any danger of getting a shock, even though the trolley pole may be left on and both canopy switches closed. This figure shows the fuse wire loose, in order that it may be more easily seen; however, the three sides *o*, *s*, *p* have a groove cut in them, and the wire is drawn into this groove.

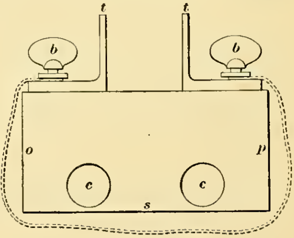


Fig. 21.

19. The General Electric Fuse Box.—Figs. 22 and 23 show one form of General Electric fuse box that is very much used. In Fig. 22, *a*, *a* are two holes through which the trunk wire passes into and out of the fuse box; on each end of the box is a hole *b*, through which a screwdriver may be put to loosen or tighten screws *b*, *b*, shown in Fig. 23 (*a*); *c* is a rawhide flap that serves as a weather protector. A substantial lid is unnecessary on this fuse box, because the presence of a magnetic blow-out coil *d*, Fig. 23 (*a*), allows very little arcing when a fuse blows. Fig. 23 (*a*) shows the member that fits into the wooden case shown in Fig. 22; *a*, *a* are two lugs provided with holes *e*, *e* to take the ends of the trunk wire and screws *b*, *b* to secure the wire in place; *c*, *c* are also two lugs provided with thumbscrews to take such a special fuse wire as is shown in Fig. 23 (*b*). This special fuse with terminals and made of regular fuse wire is not necessary, as almost any fuse wire can be secured under the thumbscrews, but it is a good thing because it makes sure that in a majority of cases the car is provided with a fuse of the proper size. On one side, *a* and *c*, Fig. 23 (*a*), are connected directly together, but on the other side they are connected through coil *d*, which has an iron core so disposed as to throw a strong magnetic field across the space *s*, where the fuse blows. This fuse box does good work when in good order and will only give trouble when continuous abuse causes the blow-out coil to become short-circuited.

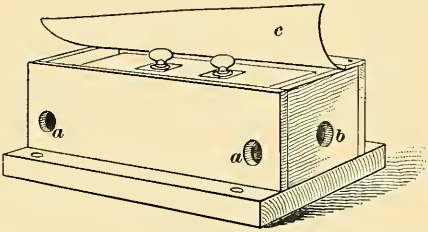
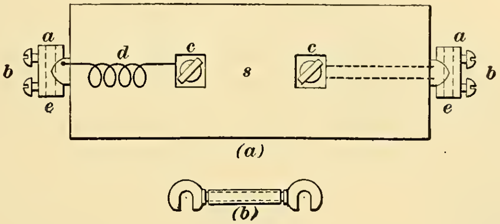


FIG. 22.



(*a*)

(*b*)

FIG. 23.

CIRCUIT-BREAKERS.

20. Circuit-breakers have been used for a number of years in street-railway power houses, but their use on street cars is of comparatively recent date. The circuit-breaker, as its name implies, is a device for opening the circuit between the trolley and ground whenever the current, for any reason, becomes excessive. On a street car they occupy the position usually taken by the hood switches; in fact, they are practically an automatic hood switch, and therefore serve the combined purpose of hood switch and fuse box. Fuses are always more or less unreliable. Sometimes they blow when they should and sometimes they do not. The circuit-breaker is essentially a switch that is held closed against the action of a spring by a catch or trip attached to the armature of an electromagnet. The current from the trolley passes through the coil that forms the electromagnet, and if for any reason the current becomes excessive, the armature is attracted, thus releasing the catch and allowing the switch to fly open. The circuit-breaker does not, therefore, depend on any heating action for its operation, and hence works almost instantaneously and with much more reliability than a fuse.

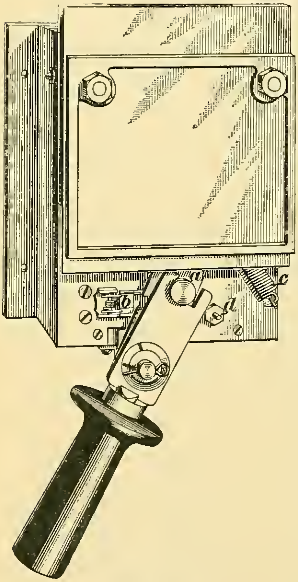


FIG. 24.

Circuit-breakers used on cars are generally arranged so that the arc formed at the break takes place in a magnetic field and is thus blown out in the same way as in a controller. Fig. 24 shows a car circuit-breaker. In general appearance it is much like a hood switch; *a* is the switch blade and *b* is the catch that holds it in position against the action of the spring *c* when the breaker is set. A blow-out coil is contained in the box, and this forms a magnetic field by which the arc is extinguished. The nut *d* is used to adjust the current at which the breaker trips, by varying the tension on a spring against which the armature has to pull.

21. Fig. 25 shows another circuit-breaker of larger capacity. This type is also used on cars equipped with heavy motors. When so used, it is in many cases mounted in a box with the handle *h* projecting at one end. *A* and *K* are the terminals of the breaker and *B* is the tripping coil, which also serves to set up the magnetic field necessary for blowing out the arc. *X* is the armature of coil *B* and is pulled down against the action of the spring *S* whenever the current exceeds that for which the breaker is set. The tripping current is adjusted by means of nut *T*. The iron plate *P* and a similar one back of it are magnetized by the current in coil *B*, and as the break takes place between these two poles, the arc is promptly extinguished by the field that exists there. Fig. 26 will give an idea as to the principle of operation. *A* and *K* are the terminals, *d d* is a contact that is forced up against *F*, *F* when the breaker is set. The current then takes the path *A*–*B*–*F*–*d d*–*F*–*K*. When the breaker trips, the contact piece *d d* flies down and the tendency is for an arc to form between *F*, *F*; the magnetic field blows the arc upwards, and whatever burning takes place is on the contacts *E*, *E*, which are so constructed that they may be readily renewed. When it is desired to trip the breaker by hand, the knob *N*, Fig. 25, is pressed.

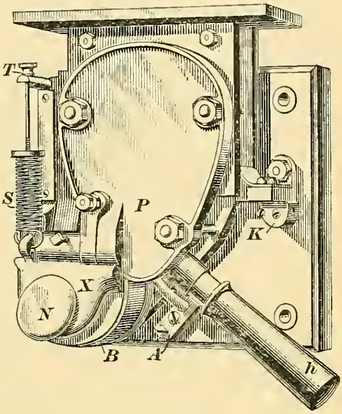


FIG. 25.

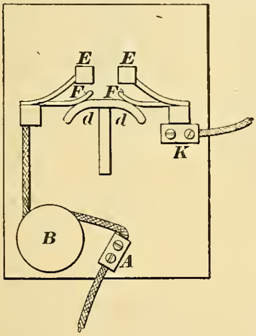
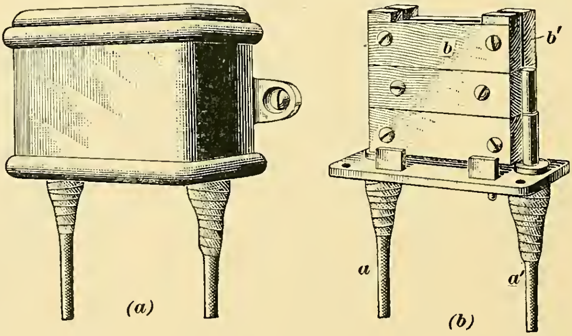


FIG. 26.

STREET-CAR LIGHTNING ARRESTERS.

22. Each car should be equipped with a lightning arrester and in some cases, on the larger cars, two arresters are provided. The arresters used on cars do not differ materially from those used for other work and which have been described previously. The arresters made by the General Electric Company are of the magnetic blow-out type and are mounted in a porcelain case. The Westinghouse car arrester extinguishes the arc that would otherwise follow the discharge by confining it between two lignum-vitæ blocks, where it is smothered out. A lightning arrester used on street-railway service is used under especially severe conditions, because every discharge to ground gives rise to a short circuit, since one side of the system is grounded. The arresters should be inspected from time to time to see that their air gaps are in good order.

23. Westinghouse Arresters.—Fig. 27 shows the Westinghouse car lightning arrester; (*a*) shows the arrester with the iron cover on and (*b*) with the cover off. The



(*a*) (*b*)

FIG. 27.

wires *a*, *a'* pass through the bottom and connect to the terminals, which are clamped between the blocks *b*, *b'*. These terminals are separated a short distance, and the space between them is bridged over by a number of charred grooves, across which the discharge leaps. Fig. 28 shows the arrester as mounted on a car in connection with a choke coil. The ordinary choke coil used on street cars consists of 10 or 12 turns of wire wound on a wooden core about 2 inches in diameter. The coil shown in Fig. 28 is wound on a grooved wooden core and bare wire is used. A copper strap is connected to the line terminal of the arrester and is placed in close proximity to the turns of wire. When a discharge comes in over the line, it can jump from any of the convolutions to the strap and thus pass off through the arrester to the ground. In the great majority of cases, however, the plain choke coil is used.

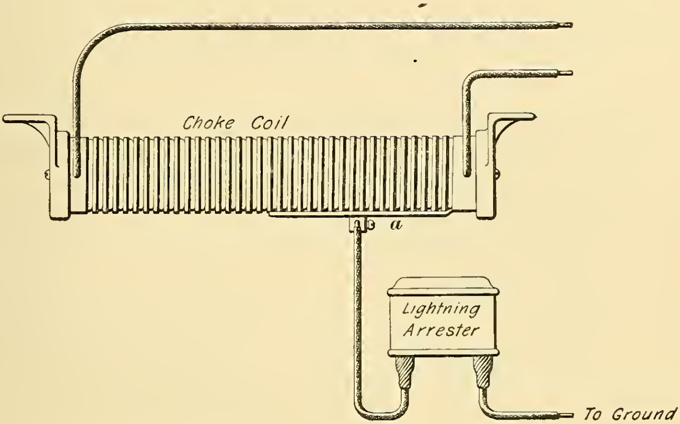


FIG. 28.

24. Inspection of Lightning Arresters.—All lightning arresters of whatever make should be inspected after each thunder shower, for even if the arresters themselves are in good shape, there may be some loose or broken connection in a wire leading to or from the arrester. If the ground wire is broken or disconnected, the arrester might just as well not be on the car at all.

The principal point to be observed about an arrester is that the air gap should be thinner or more easily punctured than any of the insulation to be found on the motors or the controllers. If inspection is neglected and, through the burning and jolting of the car, the air gap is allowed to get thicker than the insulation it is to protect, the lightning will jump through the insulation, rather than jump across the air gap.

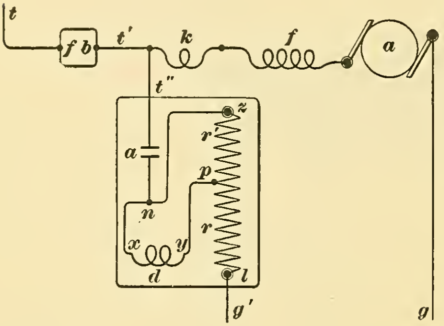


Fig. 29.

25. Connections for General Electric Arrester.—Fig. 29 is a diagram of the General Electric Company's latest type of magnetic blow-out arrester, and shows the manner of connecting the arrester. A carbon resistance $z\,l$ is divided into two parts, r' and r; part r' is in multiple with the blow-out coil d and part r is in series with both and serves to limit the value of the trolley current that always follows the discharge across the air gap a. One end of the blow-out coil d is attached to one side of the air gap and to one end of the carbon resistance at z; the other end of the coil is attached to the carbon resistance at point p. The trolley connection enters at the upper left-hand side of the case and connects to one side of the air gap. In the figure, t is the trolley wire leading *to* the fuse box; t', the wire leading *from* the fuse box; k is the choke coil; f and a, the motor field and armature, respectively; g, the motor ground and g', the lightning-arrester ground, running from the main ground wire to a post in the lower right-hand end of the box. Ordinarily, the path of the current is t–t'–k–f–a and to the ground at g; as soon as lightning strikes, it takes the path t–t'–t''–a–n–z–p–l and to the ground at g'; on reaching point n, it has two ways of getting to point p—through the carbon resistance by way of path n–z–p and through the blow-out coil by way of path n–x–d–y–p; since the blow-out coil acts as a reactance coil, the first sudden discharge prefers to take the carbon non-inductive path in multiple with it. In passing through the coil, the current sets up a strong magnetic field across the gap *a*; the arc is put out and the arrester is ready for the next discharge.

RESISTANCE COILS.

26. Reasons for Use of Resistance Coils.—The resistance coil, sometimes called the starting coil, is a device that is used to limit the value of the current at starting; this permits the car to be started smoothly without jerking and protects the motors from the undue strain that would result from an excessive current. It must be borne in mind that wherever there is resistance in a circuit through which a current flows, there is heat, and wherever there is heat, there is a loss of energy that cannot be converted into useful work. If it were not for this fact, the motors themselves could be so wound that they would have resistance enough to hold the current down to a safe value at starting; but then this resistance would, to a greater or less degree, be in circuit all the time and there would be a constant and excessive loss of energy due to heating. It is very often the case that cars run slower after they become well heated than they do when they make their early trips. This effect is very noticeable on heavy cars equipped with old-style motors. In order, then, that the equipment shall waste as little power as possible, the resistance of the motors is made very low; on account of this very low resistance, the line pressure of 500 volts would send through the motors an enormous starting current that would not only start the car with a jerk, but would strain the motors and gearing; to do away with these two bad effects, the starting coil is used. This coil is intended to be used only on the starting notches of the controller; when the running notches are used, the coil is entirely cut out and cannot, therefore, have any effect upon the maximum speed of the car.

27. Running Cars on Resistance Notches.—It is a very bad practice to run a car for any length of time on a resistance notch. There are three reasons for this: in the first place, it is not an economical notch on which to run, because the heating of the coil means just so much energy wasted; in the second place, the coil is designed only for the temporary use of starting, and when continuously used for slow running, it gets so hot that the insulation is destroyed, the coil is short-circuited, and the car is made to start with a jerk; in the third place, accordingly as one running notch or the other is used for running purposes, one part or the other of the coil will be abnormally heated.

28. General Electric Resistance Coil.—Fig. 30 shows a type of starting coil made by the General Electric Company. It consists of ordinary band iron folded back and forth with a ribbon of asbestos in between each fold. This iron and asbestos is built up into divisions *d* called panels, and these divisions are held in insulating bricks *a* and clamped firmly by means of the end plates *b*, *b* and bolts *c*. The whole is hung from the car floor by means of the feet *e*, *e*. The terminals of the different sections into which the resistance is divided are connected to the binding posts *f* that receive the wires that come from the car hose and connect to the two controllers. For resistances used in connection with heavy traction work, a similar construction is followed, except that instead of a folded iron strip insulated with asbestos, a cast-iron zigzag grid is used. This makes a very substantial and well-ventilated resistance.

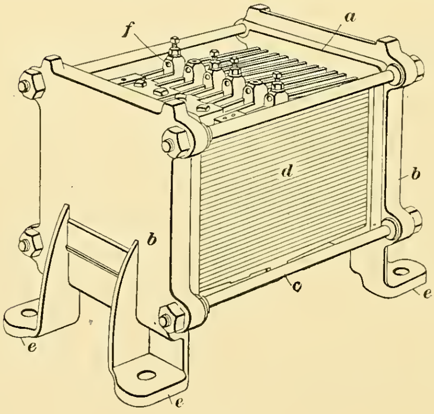


Fig. 30.

29. Westinghouse Resistance Coil.—In Fig. 31 is shown the type of resistance coil made by the Westinghouse Company. This coil is made of band iron insulated entirely with mica, and up to certain limits of abuse it is not affected by either heat or water. A single coil, such as that shown in the figure, is called a barrel, and the proper starting coil for any size motor can be made up of two or more of these barrels. Fig. 32 shows the method usually adopted for hanging a two-barrel starting coil. Where more barrels are required, more sets can be hung in the same manner alongside one another. In Fig. 32, *a*, *a* are two of the car sills; *b*, *b* are two strap-iron hangers through which passes a rod *d d* supporting coils *c*, *c*. Fig. 33 shows Westinghouse resistance coils mounted in an iron frame.

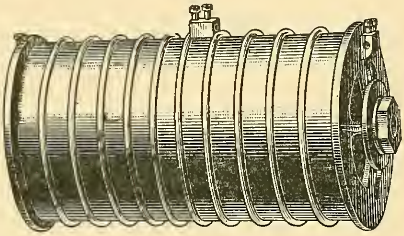


FIG. 31.

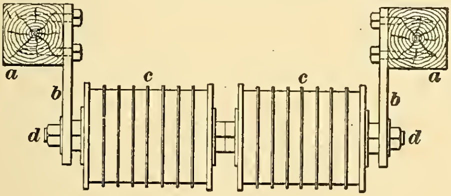


FIG. 32.

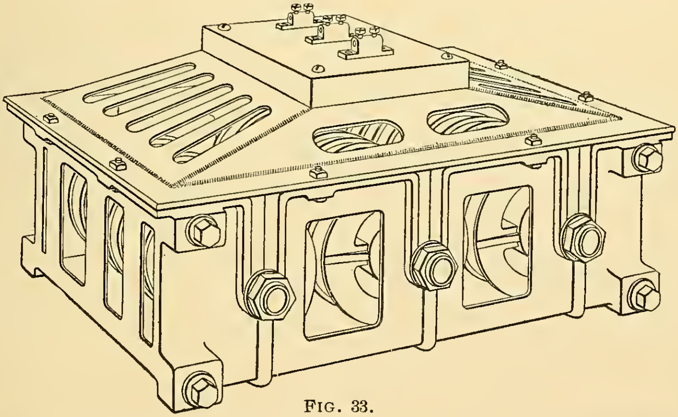


FIG. 33.

ELECTRIC CAR HEATING.

30. Introductory.—So far we have confined our attention to the uses to which electric current is put for driving the cars. Current is, however, also used for heating and lighting them, and it is necessary to consider the appliances and methods used for this purpose. It has already been explained that if a current is sent through a wire, it always encounters a certain amount of resistance and the wire becomes heated. If the power used in forcing the current through the wire is large, the temperature of the wire will be high and the wire may be brought to a red or even a white heat. When the heating effect is sufficient to bring the conductor to a white heat, light is produced, as in the case of the incandescent lamp. In ordinary line wires, there is a heating effect, but the resistance of the wire is so low that the rise in the temperature of the wire is not noticeable. When the temperature is very high, as in an incandescent lamp, it is necessary to mount the conductor or filament in a vacuum, so that there will be no oxygen present to oxidize it. In electric heaters this is not usually necessary, as the temperature at which the wire is worked under normal conditions is not high enough to cause damage.

31. General Remarks on Heater Construction.—All electric heaters are made on the same principle—that of enclosing a high-resistance wire in a case that is designed to keep the feet and clothing of passengers out of range of the hot wire. According to the size of the car and the make of the heater, 4, 6, 8, 10, 12, or even 20, heaters are required per car. For a given amount of heat required, the smaller the heater and the more of them that are used, the more evenly will the heat be distributed through the car, but the more places will thus be created where trouble is liable to arise.

As regards efficiency, heaters of all makes are about the same. To keep a 20-foot closed car comfortable during average weather in the vicinity of New York requires a current of about 10 amperes at 500 volts. This means that between 6 and 7 horsepower is used to heat a car. It is easily seen, then, that it costs considerable to heat a car by electricity and that when the heaters are in use, there is a considerable additional load thrown on the station. On the other hand, electric heaters occupy no passenger space, they distribute the heat more uniformly than stoves, they are cleaner, and they allow the heat to be more easily regulated. For these reasons, the electric heater is extensively used, even though it is more expensive to operate than a coal stove. Electric heaters are nearly always installed in such a manner that at least three different degrees of heat may be obtained by operating a **heater switch** that changes the connections of the heaters.

The number of different makes of heaters is so large that it would be out of the question to treat all of them here. We will, however, describe one or two typical examples in order to illustrate the method of connecting. The connections for the different makes are much the same.

EXAMPLES OF ELECTRIC HEATERS.

THE JOHNS HEATER.

32. In the **Johns** system of car heating and in most other systems, the heaters are distributed through the car. In cars in which the seats run lengthwise, the heaters are hung along the seat panels on both sides; in cars with cross seats, they are placed under the seats. The resistance wires of the Johns class E heaters are completely covered with asbestos thread and are then woven into a mat, the warp of which consists of asbestos cords. The heater thus formed is thoroughly impregnated with a special insulating compound baked in at a high temperature and is thus made waterproof. The heater is then attached to a backing of asbestos millboard that has been prepared in the same way. The completed heater is put in a perforated steel casing and the electrical connections are made by means of binding posts on porcelain bases at each end of the heater.

33. Connections for Johns Heaters.—Fig. 34 gives the general outline of the Johns class E heater and also shows how the wires on the inside are brought out to the binding posts *O*, *O*, *O*, *O*; the resistance wire in the heater is in two parts that do not touch each other anywhere. In Fig. 34, *A* is the top part and *B* the bottom part; the binding posts to which they connect are set on porcelain bases *M*, which, of course, keep them apart. Wires *A*, *A* and *B*, *B* on the ends connect the heaters together on the inside of the panel, as shown in Fig. 35, which is a section of a closed-car seat with a class E heater mounted upon it. In Fig. 35, *A* and *B* are the wires by means of which the heaters are connected together; *H* is the heater; *P*, a cross-section of the seat panel; and *S*, a space between the back of the heater and the face of the seat panel.

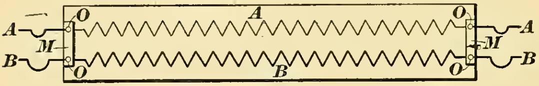


FIG. 34.

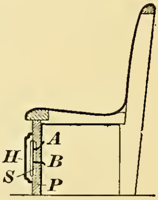


FIG. 35.

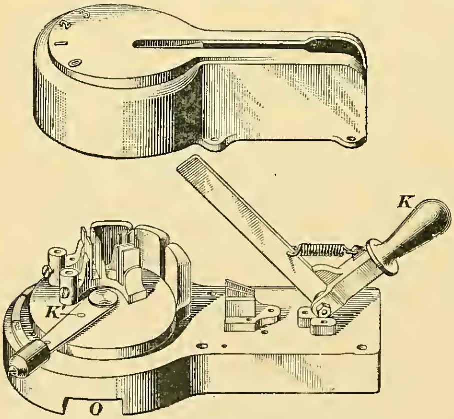


FIG. 36.

34. The Johns Regulating Switch. Fig. 36 shows the Johns heater switch. The main point about this switch is that before any change can be made in the combination in which the heaters are running, the main heater circuit must be opened. In Fig. 36, switch *K* opens and closes the heater circuit and blade *K'* makes the combinations corresponding to the several marked notches indicated by the dotted lines on the heater case in Fig. 37. By such an arrangement, all tendency to blister and burn is confined to a quick-break knife switch that will not be damaged to any extent by it. As long as the knife switch is open, the current is off and the regulating switch *K'* can be moved to any of the four notches without danger of burning; but when *K* is closed, *K'* cannot be moved at all; also, unless the regulating switch is exactly on the notch, switch *K* cannot be closed.

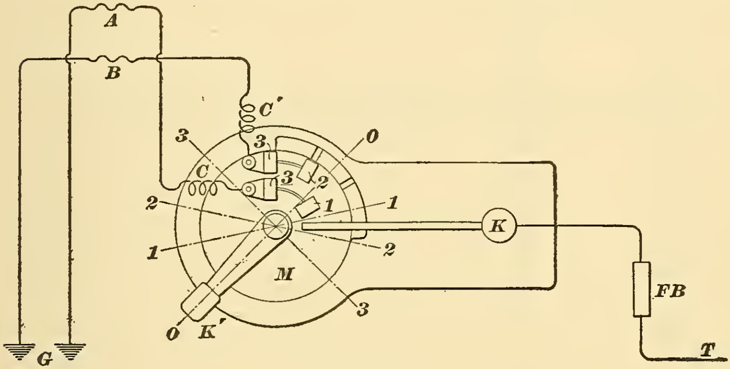


FIG. 37.

35. Fig. 37 is a diagrammatic sketch of the connections of the Johns heater switch. In the figure, the switch is at the off-, or *0–0*, position, so that no current can flow through

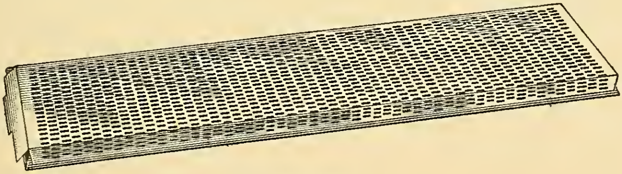


FIG. 38.

the circuit; when *K* is open and *K′* is turned to the first notch, indicated by the dotted line *1–1*, contact jaws *1*, *2*, and *3* swing with *K′* and jaw *1* falls into line with *K*, so that when *K* is closed, the path of the current is *T–F B–K–1–3–C*, through the top or *A* part of every heater, to the ground at *G*. When *K′* is moved to the second notch, jaw *2* falls into line with *K* and the path of the current becomes *T–F B–K–2–3–C′*, through the *B* or bottom sections of all the heaters, to the ground at *G*. On the third notch, both jaws *3* fall into line with *K* and the current divides between the *A* and *B* sections of all the heaters. Jaws *3* do not touch each other, but each connects to a binding post to which the heater circuits connect. Fig. 38 is a view of the class E Johns heater, complete, ready to be put in a closed car.

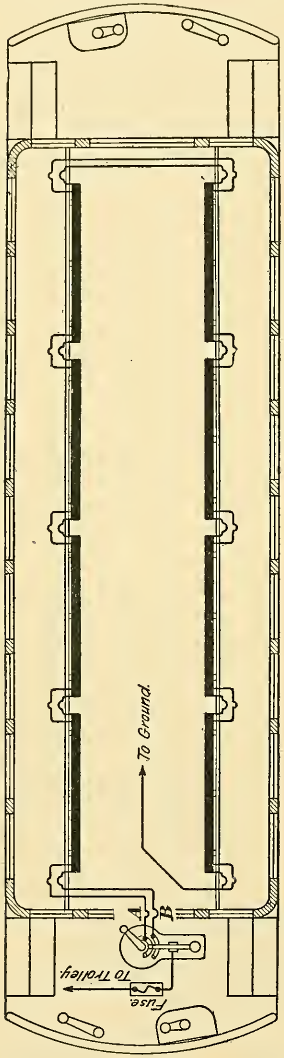


Fig. 39.

36. Car Wiring for Johns Heaters.—Fig. 39 is the car-wiring diagram for a set of class E heaters, eight to a set; the top section of each heater connects to the top section of the heater next to it, and so on all around the circuit. Care must be taken that the top and bottom wires are not confused.

THE CONSOLIDATED HEATER.

37. Construction.—Fig. 40 shows the coil used in the consolidated heater, and which is constructed as follows: On a stout iron rod are strung porcelain tubes that run the full length of the heater. These pieces have a spiral groove in them and are put on the rod so that a continuous spiral groove runs the full length of the core. The heater coil is placed in this groove. This way of arranging the coil places a great amount of wire in a given space and gives the air a good chance to get at all parts of it. The terminal wires that run out of the case at each end, through porcelain bushings, are attached to the ends of the coil by twisted and soldered joints and are well secured without the aid of binding posts. In each heater are two coils, like that shown in Fig. 40, placed one above the other. The top coil has the greater resistance.

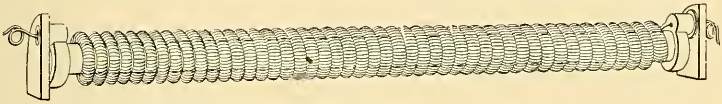


FIG. 40.

38. Fig. 41 shows the type 143L heater with the front plate removed to show the two coils in place. The 143L heater is for a side-seat closed car and is intended to be set flush with the panel of the riser.

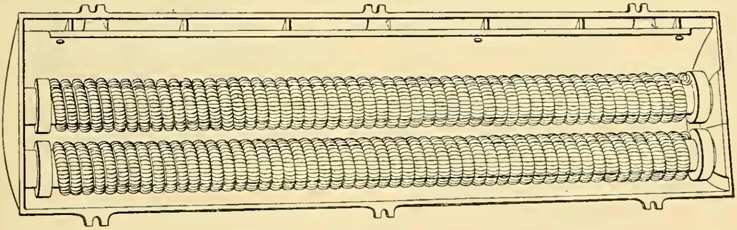


FIG. 41.

The wiring for these heaters is carried out as shown in Fig. 42.

39. Consolidated Heater Switch.—Fig. 43 shows the heater switch with the cover on and off. This switch will handle 30 amperes at 500 volts. The spring-brass contact plates are mounted on a glazed porcelain base and the arm of the switch is of composition insulating material. The position on which the switch rests is clearly shown by a dial number that appears through a hole in the cover. In both views of Fig. 43, the switch is on the third point; on this point, the current goes in on the right-hand side of the switch at the post marked *T*. The three arms *a*, *b*, *c* are all connected together so that the current splits; part of it goes across the *b* arm to post *1* and thence to the circuit through the top part of all the heaters; the other part goes across arm *c* to post *2* and thence to the circuit through the

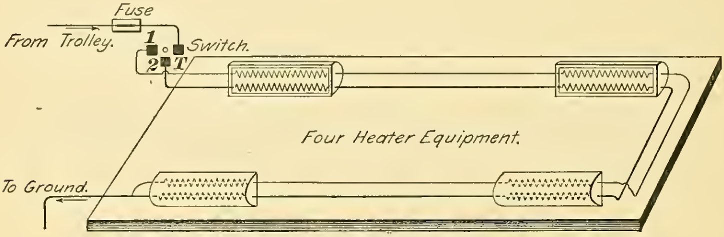


FIG. 42.

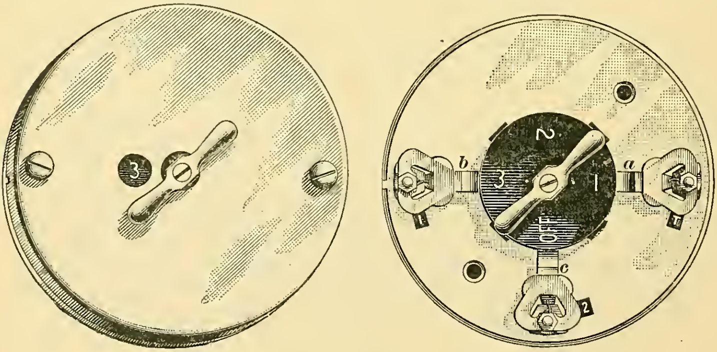


FIG. 43.

bottom part of all the heaters. If the handle be given a quarter-turn to the right, arm *a* leaves post *T* and goes to post *2*; arm *c* leaves post *2* and goes to post *1*; arm *b* leaves post *1* and does not go to any post at all; so post *T* is left without any connection and the switch is dead except on post *T*. If the switch is given another quarter-turn, arm *a* goes to post *1*, arm *b* goes to post *T*, and arm *c* leaves post *1*, but does not go to any post at all, so that current can only flow through the top of the heaters, which is the combination on the first point. One more quarter-turn takes arm *b* from post *T* to post *2*, arm *c* to post *T*, and arm *a* from post *1* to no post at all. On this point, then, post *1* has no connection and current flows through only the bottom part of the heaters.

40. Troubles With Heaters.—Figs. 44 and 45 show how simple mistakes may cause trouble. In Fig. 44, H, H_1, H_2, H_3 are four heaters in series across the line and the path of the current through them is $T-H-H_1-H_2-H_3$ to the ground at G. When connected thus, these heaters take all the current that they should have. Now, suppose that on account of some poor wiring, the wire joining heaters H_1 and H_2 comes into contact with a truss rod, brake rod, sand box, etc., making a ground at G'. The current goes through the top part of all the heaters the same as it did before, because that is not grounded, but the path of the current through the bottom sections becomes $T-H-H_1-G'$; two heaters H_2 and H_3 have their lower sections cut out entirely, and the lower sections of heaters H and H_1 are across the line alone. The result is that these sections burn out.

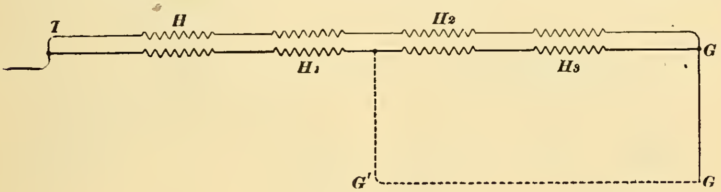


FIG. 44.

Fig. 45 illustrates a case of getting the top and bottom heater leads confused. The upper sketch (*a*) shows six heaters connected as they should be. In Fig. 45 (*b*), all the heaters have been connected properly except the last one, where the top and bottom leads have been crossed, with the result that the fine-wire coil in the H_5 heater is in series with the coarse-wire coils in all the other heaters, and the H_5 coarse-wire coil is in series with the fine-wire coils in the other heaters. This is not so hard on the fine-wire coils in series with the H_5 coarse-wire, because the effect is shared by each of the five heaters ahead of the fault; but it is hard on the H_5 fine-wire coil, because the five coarse-wire coils with which it is in series pass more current than it can stand. The result is that unless the trouble is found in time, the top part of the H_5 heater will become red hot and burn out or it will melt its soldered connection.

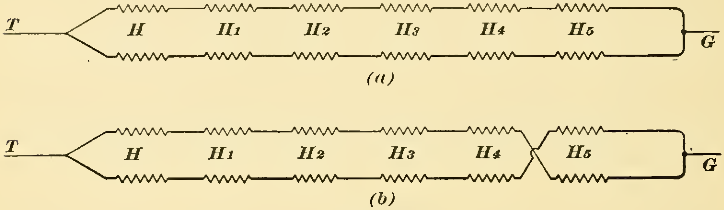


FIG. 45.

CAR LIGHTING.

THE LAMP CIRCUIT.

41. General Remarks.—The lamp circuit is one of the most important parts of a car's equipment, and it may be of great assistance to the crew if they know how to use it. In the first place, if the lamp circuit is kept in such condition that it may always be relied on to burn when there is any power on the line, it becomes a ready means of telling if the power is on or not. If a car refuses to move and if there is no flash in the controller when the power drum is thrown on and off, the next thing to do is to turn on the lamp switch to see if the lamps will burn; if they burn, the power is, of course, on the line, and the car's failure to move must be due to a fault in the motor circuit. Though if the lamps do not burn, it is by no means safe to draw the conclusion that no power is on the line, because their failure to burn may be due to a fault in the lamp circuit itself. The two places where such a trouble most often occurs are where the ground wire is fastened to the truck or motor and in the main light switch, if there is one, that controls all the lamp circuits. The main seat of trouble, though, is in the ground wire; never fasten the lighting ground wire to the motor or to the truck.

42. Switches for Car-Lighting Circuits. — Fig. 46 shows a type of single-pole lamp switch that is largely used. It can be used to control a single independent circuit or any number of circuits within its capacity, if all the circuits can be put in multiple. The lamp wires pass under the porcelain base through two grooves made for that purpose and come up into posts *l*, *l*, where they are held by screws. When the key *h* is turned to the right, spring *p* winds up as far as possible and switch blade *k* then jumps loose from contact

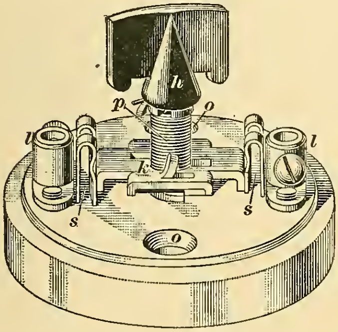


FIG. 46.

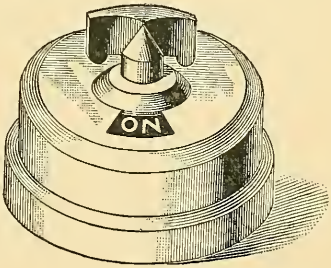


FIG. 47.

tips *s*, *s* and breaks the circuit in two places. Fig. 47 shows the appearance of a switch with the cover on.

43. Fig. 48 shows an ordinary three-way switch that is commonly used on cars for cutting the headlight out and the tail-light in, or *vice versa*. On the switch shown in Fig. 48 there are, besides the switch blade *k*, four spring contact clips L_1, L_2, L_3, L_4, three of which have a post to take a car wire and one of which, L_1, has no post. Inside the switch base, L_1 is connected to L_2; the trolley wire goes to the post on L_2, so that there are on the switch two trolley posts L_1 and L_2, and no matter in what position *k* may be, one end of it is bound to make contact with a trolley post. When *k* is in the position shown in the figure, the current comes in at L_2, goes over to L_1 by way of the inside connection, crosses *k*, and goes out on the L_3 wire. If *k* is given a quarter-turn, the current comes in on L_2, crosses on *k*, and goes out on the L_4 wire. When controlling two independent circuits or when used to cut in and out alternately two parts of the same circuit, the three-way switch has no off-position.

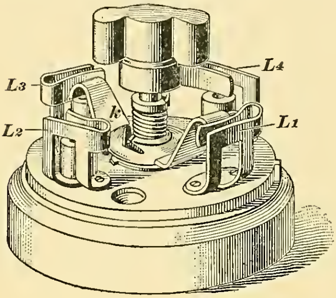


Fig. 48.

44. Westinghouse Plug Switch.—Fig. 49 shows the Westinghouse Company's three-way plug switch. *A* is a disk of hard rubber about 3½ inches in diameter and about 1¼ inches thick. In it are three metal-lined holes *T*, *1*, *2*, each with a metal bottom. By means of posts not shown in the figure, one circuit is attached to the metal sheathing of hole *1* and the other to that of hole *2*; the trolley wire connects to the sheathing of hole *T*. *B* is a **U** plug with a rubber handle; holes *1*, *2*, and *T* have no connection with one another until plug *B* is shoved into place; if *B* is put into the two left-hand holes, the current comes in on wire *T* and goes out on wire *1*; if *B* is put into the two right-hand holes, the current comes in on wire *T*, as before, and goes out on wire *2*. If plug *B* should get lost, a piece of No. 4 B. & S. rubber-covered wire bent into a **U** will answer.

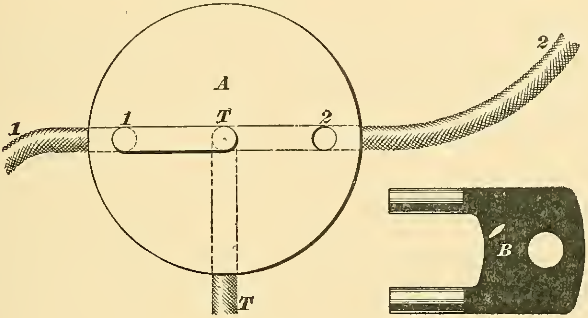


FIG. 49.

CONNECTIONS FOR LAMPS.

45. Single Lamp Circuit.—The lamps used for lighting cars require from 100 to 110 volts across their terminals; hence, in order to operate these lamps on a 500-volt circuit, they must be arranged so that there will always be five in series between the trolley and ground. It is not practicable

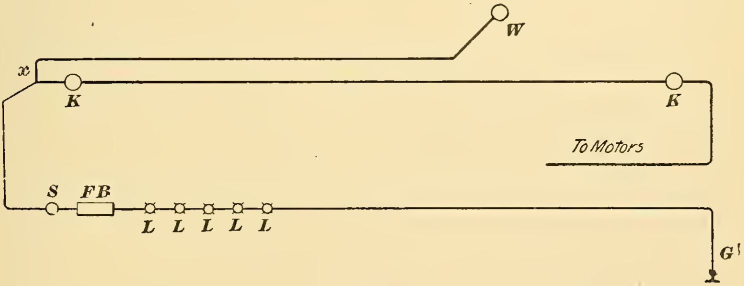


FIG. 50.

to make lamps that will burn directly across 500 volts. Fig 50 shows a single five-light lamp circuit with all the lamps inside of the car; in such a case, an oil headlight or sign light must be used. The lamp circuit is tapped to the trolley roof wire ahead of both hood switches, so that the opening of either of these switches will not put out the lamps. *S* is a single-pole snap switch and *F B* the lamp fuse box.

46. Fig. 51 is the wiring diagram for a double-circuit car that has eight lamps inside, two headlights, and two tail-lights. The Westinghouse type of switch is selected on all the diagrams given here, because it is so much easier to follow the path of the current through it. When the **U** plug is in the two top holes, the headlight burns; when it is in the two bottom ones, the headlight is cut out and the tail lamp burns. *S* is the usual snap switch for cutting off the current. There is a ground wire and a trolley wire on both ends of the car, but there is no unbroken wire running the full length of the car. There is a snap switch and a three-way switch on each circuit, which may be put on the same end or on opposite ends of the car, as they are in the figure. If it is desired to control both circuits from the same end of the car, as shown in Fig. 52, two more wires must be run the full length of the car, in order to connect the three-way switch with the headlight and tail-light at the far end. The

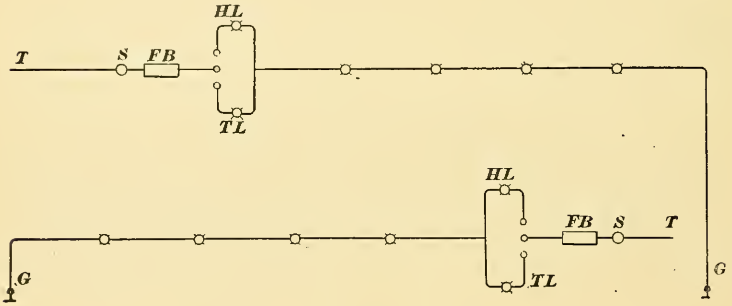


FIG. 51.

lamps inside the car are here shown in straight rows, though they may, of course, be grouped in any desirable manner.

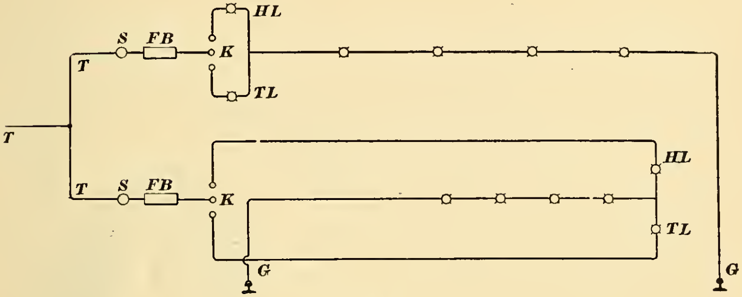


FIG. 52.

Switches *K* and *K* may be plugged so that both of the headlights or both of the tail-lights will burn.

47. Fig. 53 shows one style of lamp wiring to be used on elevated or on converted steam roads, where not only are headlights needed, but markers as well. The markers are supposed to show a red, green, or white light, or some combination of the two, to indicate the destination of the train.

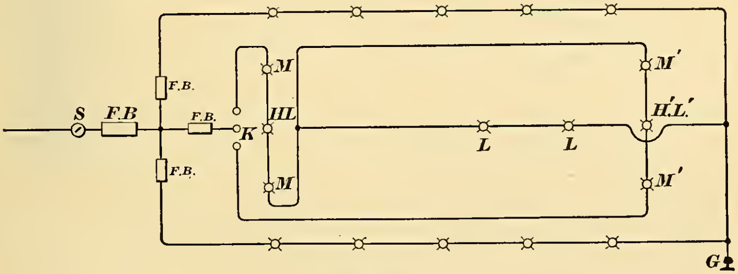


FIG. 53.

In Fig. 53, *M*, *M* and *H L* are the markers and headlight on one end of the motor car; *M'*, *M'* and *H' L'* are the same on the other end of the car. *L*, *L*, the two lamps inside of the car, are in the form of a two-light cluster, and burn whenever the signal lamps on either end of the car burn.

DASH LIGHTS AND HOOD LIGHTS.

48. In the wiring diagrams shown, the headlights have been placed on top of the bonnets of the cars; when so placed, they are spoken of as **hood lights.** But headlights are not always put on top of the hood; on many roads, they are set into a round hole cut in the center of the dash iron; when so placed, they are spoken of as **dash lights.** Fig. 54 gives a general idea as to how a headlight sets into the dash. The style shown is known as the **pot headlight.** *A* is the dash rail; *I*, the iron; *F*, the floor; *H L*, the headlight whose cover *C* swings outwards; *P*, an iron pipe, through which the wires are run to the lamp socket.

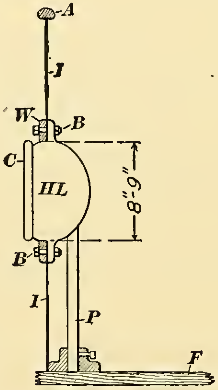


FIG. 54.

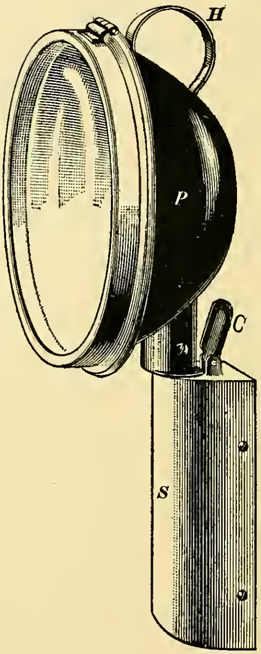


FIG. 55.

49. The dash light is not always set into a hole in the dash iron. There is one type of dash light, of which a large number are in use, that sets outside of the dash iron in a socket on the bump block. There is a socket on each end of the car and but one headlight is used on each car. When the car turns at the end of the road, the dash light, of course, stays on the same end; but if the car does not turn, the headlight must be drawn out of the socket on one end and dropped into the socket on the other end. In Fig. 55, *P* is the changeable part of the outfit; *S* is the socket or receptacle, which is a fixture on the car, and *C* is a cap or cover that is to be shut down as soon as *P* is drawn out of *S*.

50. Changeable-Headlight Wiring Diagram.—Fig. 56 shows how two interchangeable headlights are wired in a five-lamp circuit; the headlight, of course, has a lamp *7* of its own, and according as the headlight is on one end of the car or the other, lamps L_1 or L_5 are cut out and replaced by *7*. In this figure, the headlight is in place on the right-hand end of the car and car lamp L_5 is cut out. The path of the current is $T-S-FB-1-2-3-4-L_1-L_2-L_3-L_4-5-6-7-8-9-10-G$. In the side of the tongue of the headlight that goes into the socket are two contact plates, shown at *o* and *x*, to which are connected the two wires from the posts of lamp *7*. At *S* and *S'* are shown the two springs that make contact with these two plates when the tongue is shoved into the socket. Springs *S''* make a path for the current to go through when the headlight on that end of the car is not in place. As soon as the tongue is dropped into the socket, its end forces the two springs apart and the current flows through the headlight.

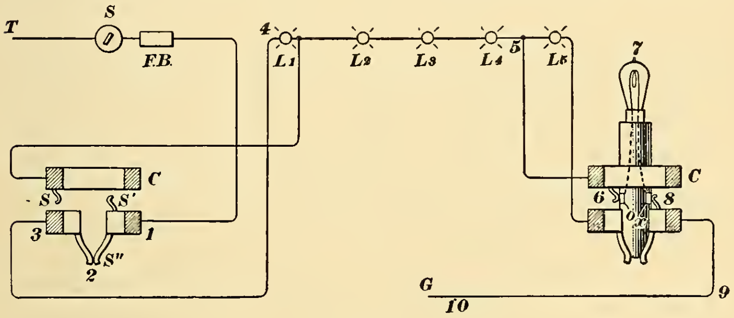


FIG. 56.

51. Changeable Headlight on a Two-Circuit Car.—Fig. 57 shows a light-wiring diagram for an interchangeable headlight to be used on a car that has two five-lamp circuits. The removal of the headlight from either end of the car

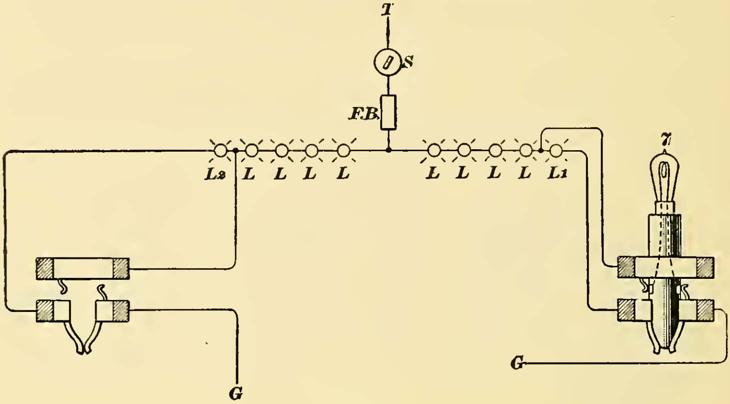


FIG. 57.

automatically cuts the fifth car lamp into circuit on that end to take its place.

BRAKES.

INTRODUCTION.

52. One of the most important items in the equipment of a car is the brake. Most of the cars in common use are equipped with **hand-brakes,** in which the brake shoes are forced against the wheels by a system of levers operated by the handle under the control of the motorman. The general tendency has been to increase the weight and size of cars, and hand-brakes have in many cases been found inadequate to control them. This has resulted in the introduction of **air brakes,** in which the shoes are pressed against the wheels by means of a piston connected to a series of levers; this piston is operated by means of compressed air. Another type of brake which as yet has not been used very extensively is the **momentum brake,** in which the force necessary to press the shoes against the wheels is supplied by the energy stored in the moving car.

53. On cars rigged with hand-brakes, the brake handle is the force arm of the first lever of the series of levers that press the shoes against the wheels. Fig. 58 is a sketch of the parts involved in this lever. The amount of pull on the rod depends on how much longer the brake handle is than the radius of the drum and on how much of a pull the motorman is able to exert at *P*. Suppose that the brake handle is 14 inches long. Call the diameter of the drum 1½ inches. When a brake chain made of ⅜-inch stock is wound up on this drum, the average diameter of the wrap of chain will be about 2¾ inches; one-half of this diameter, or 1⅜ inches, is the short arm of the lever of which 14 inches is the long arm, making the leverage of about 10 to 1. Some men are able to pull on a brake handle much harder than others. We will assume that the average man can exert a maximum pull of 200 pounds. The pull exerted on the brake rod will then be 2,000 pounds.

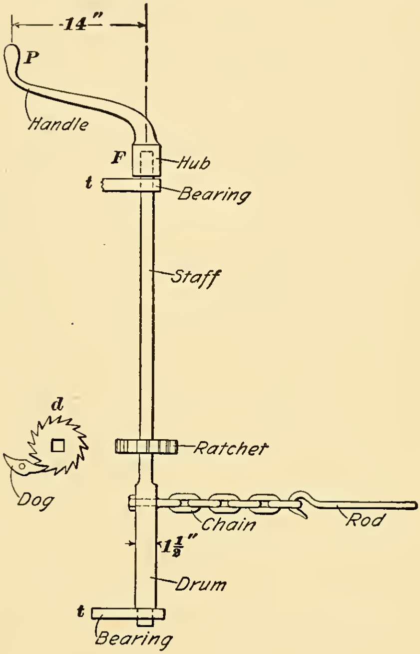


FIG. 58.

54. Shoe Pressure.—The amount of pressure required to brake a car depends on the weight and speed and on the number of wheels that have shoes applied to them. If a car has eight wheels and the brakes are applied to four of them, the pressure per brake shoe must be the same as would be necessary were all the wheels supplied with shoes, because the braked wheels carry only one-half the total weight of the car; the maximum pressure to be applied to a wheel depends on how much weight the wheel supports. To avoid sliding, the pressure applied to a wheel should be a little less than the weight it supports.

55. Friction.—The amount of pressure necessary to cause a wheel to slide depends, of course, on the amount of friction between the shoe and wheel. How much of the pressure applied to a wheel is useful in stopping a car depends on the nature of the material of the shoe and wheel. Some car wheels are soft and others hard; the same is true of brake shoes. For a given hardness of wheel, a soft shoe will give more friction at a given pressure than a hard one, but it wears out sooner. Also, the amount of friction between a shoe and wheel changes with the speed of the car. The friction increases as the speed decreases, so that at high speeds a much greater pressure can be applied without sliding the wheel than at low speeds; from this it follows that in bringing a high-speed car to a stop, the brake should be eased up a little as the car slows down. Under different conditions of speed and brake shoe and wheel composition, the friction between the shoe and wheel varies from 15 to 35 per cent. of the applied pressure; that is to say, if a pressure of 10,000 pounds were applied to the shoe, only 15 per cent. of this possibly might be accounted for as retarding the car.

56. It is a well-known fact that the friction between a shoe and wheel is independent of the amount of surface exposed between them. For a given total pressure applied, the effect of varying the surface of a brake shoe is simply to vary the pressure per square inch; this is true when the wheel is perfectly round and the shoe truly concentric with it. There is, however, a growing tendency to use long brake shoes, because they not only tend to keep the wheel round, but since the pressure per square inch is less, they last longer.

57. Condition of Rail.—An important factor to be considered on trolley roads is the condition of the rail. The **T** rail on steam roads is mostly laid in the open country and offers very little inducement to the accumulation of snow and slush upon its top. Where a **T** rail is used in trolley-road construction, it has the same advantages. Trolley roads have paving conditions to contend with and must use a girder rail, whose flat top and open groove are very inviting to foreign substances.

When the rail is slippery, it is an easy matter to apply too much brake pressure, thereby causing the wheels to slide and make flat spots on them. To offset the disadvantage of a slippery rail, it is the custom to use sand. The use of sand greatly improves the rolling friction between wheels and rail, but most managements make the mistake of sanding only one rail instead of two. With sand on one rail, the rolling friction averages 30 per cent. of the weight on the wheel.

58. When a car rests upon a rail, there is a certain amount of friction between the wheels and rails, and this friction increases as the weight on the wheels increases. It would take a certain number of pounds pull on the rim of a wheel to turn it against the friction of the rail without moving the car. Also, when the car is in motion, if, in the effort to stop the car by means of the brakes, the latter are set up so tight as to lock the wheels and cause them to slide, the friction between the wheels and rails tries to make the wheels roll again. It is this friction that in the previous article was said to be 30 per cent. of the total weight of the car. The total pressure to be applied to the brake shoes depends on the leverage of the brake rigging, on its condition, and on the pull on the brake handle. The fraction of this pressure that actually retards the motion of the car depends on the friction between the shoes and wheels.

59. Fig. 59 shows a very common form of single-truck brake rigging, most of the parts of which are designated in the figure. Brake beams *B*, *B* are supported on the ends and slide in cast-iron pieces fixed to the side frames of the truck; they are called *brake-beam castings*. Fig. 60 shows the general idea. *A* is the slide casting, *B* the beam, and *F* the truck member that supports the casting. Equalizer rods *r*, *r* (see Fig. 59) connect to equalizer bars *E*, *E* and are erroneously said to equalize the pressure on all brake shoes. Under the most favorable circumstances, they partially equalize the pressures against the two wheels on the same axle. Each equalizer rod ends in a jaw *J*, to which the equalizer bars are rigidly connected, but in which the brake beams move freely. Fig. 61 shows the construction. *R* is the rod; *J*, the brake jaw; *B*, the beam; and *E*, the equalizer bar. In Fig. 59, links *H*, *H* are connected to the brake levers *L*, *L* and equalizer bars by means of pins. Links *I*, *I* connect the brake lever and brake beams. *F* is a pin around which *L* and *E* can move and F_1 is a pin in common to *L* and *B*. In the diagram, the brakes are shown to be off and the shoes have been pulled away from the wheels by the release springs. One end of each

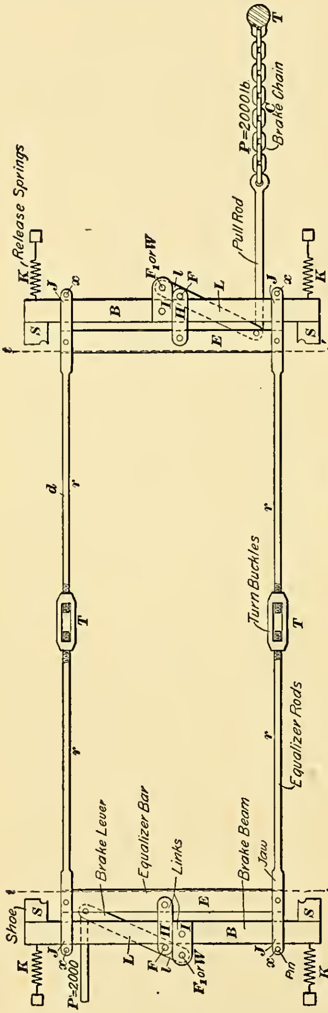


FIG. 59.

spring is fixed to a lug on a car truck and the other end to the brake beam or shoe head. Brake slides wear badly and give trouble in winter time by getting stopped up with frozen mud; the main objection is that the harder the brakes are set, the harder the brake beams press against the brake slide castings, with the final result that the harder the brakes are set, the harder it is to set them. The operation of the brake will be apparent from an examination of Fig. 59. The force exerted on the pull rod *P* draws the brake beams *B*, *B* together, and thus presses the shoes *S*, *S* against the wheels.

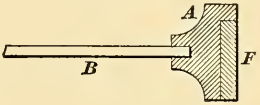


FIG. 60.

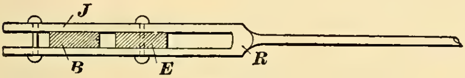


FIG. 61.

POINTS ON CARE OF RIGGING.

60. The main points to be observed in caring for brakes on single trucks are the following: See that all brake-staff bearings are kept lubricated. They should be oiled frequently, using but little oil at a time, to avoid soiling the passengers' clothes. The brake-staff ratchet wheel should not be allowed to run with teeth missing nor should the dog be allowed to have a blunt point; both should be renewed as soon as defective. Particular care should be taken to see that the action of the ratchet brake handle is perfect. If the handle ever fails to catch while being applied and the clicking noise emitted on release seems to be weak, it means that the dogs inside the handle hub have become blunt or that the springs pressing them into the ratchet have become weak; such a condition should be reported at once, as it is liable to cause a serious accident.

61. Should the brake handle appear to be much harder to turn at one point of its revolution than at all others, it probably means that the brake staff is bent. To avoid this, the brake staff should be well supported on its lower end, where the greatest strain comes. The brake chain should be fastened to the staff, so that it will wind upon the staff and not on itself; otherwise, the leverage will decrease as the brakes are applied. In case there are any tripod brackets to support the lower end of the brake staff, care should be taken that the legs of the brackets are so disposed as not to interfere with the winding up and paying out of the brake chain.

62. Inspection of Parts.—All brake-chain fastenings should be inspected every day. Every small amount of wear weakens a chain, and it is only a question of time when it will get weak enough to break. Defects are often caused by some rod or lever rubbing on a part of the car or some other device. When a brake rod is interfered with, the friction not only puts extra work on the motorman, but it may also put so much work on the release springs that they become useless. The constant rubbing will weaken the rod, so that in course of time it will break. All rods and levers may clear everything when the car is light and interfere with each other or some part of the motor rigging when the car is loaded. A rod may clear a wheel of one type and interfere with another whose dish is greater. An excessive end play in the axle collars will let the motor over against the brake rods. An excessive load on a car whose springs have become weak may let the rods down on top of a gear case or motor. In placing or inspecting a set of rigging, all these points must be kept in mind, making due allowance for the effects in the increased weight on the car body, weakening of the truck springs, and wear on the moving parts of the brake rigging. All turnbuckles, brake slides, fulcrums, and, on double-truck cars, the strap hangers, in which parts the brake rigging slides, should be kept lubricated. Release springs should be renewed when they become too weak to pull the shoes to off-position.

DOUBLE-TRUCK HAND-BRAKES.

63. Single-truck and double-truck brake riggings differ in two and sometimes three respects. A double truck consists of two single trucks, each of which has a complete set of brakes of its own. Both of these trucks revolve around independent centers, so that means must be provided to preserve the efficiency of the brakes whatsoever may be the angle that either truck makes with the center line of the car body. The third feature of difference depends on whether all the wheels on a truck are the same size or not. If they are, constituting what is known as an ordinary double truck, each of the eight wheels on the car has the same weight resting upon it, so that each shoe must have the same pressure applied to it. If, however, the truck has two large wheels and two small ones, constituting the so-called maximum-traction truck, the truck is so disposed that the large wheels support from 60 to 70 per cent. of the weight of the car.

64. Fig. 62 shows a truck rigging, the action of which explains itself. If the shoes are properly adjusted, a pull of 2,000 pounds at *P* will give each shoe a pressure of 5,000 pounds, if the leverage of *PFW* is 10 to 1, bearing in mind that the figure shows the rigging on only one side of the truck.

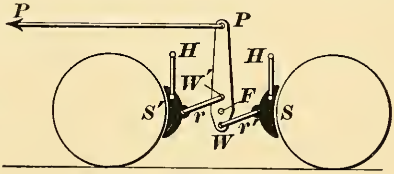


FIG. 62

65. Fig. 63 shows two such truck riggings adapted to a double truck; the long lever *PP* is secured to the car body through fulcrum *F*, which is, therefore, stationary. Fig. 64 shows the device used to compensate for the rotation of the truck on curves. *C*, *C* are two pieces of steel bent to an arc to suit the rotation of the truck. These bent pieces of steel are variously called "circle bars," "arch bars," and "existing arches," and the pull rods from the respective trucks connect to their ends. Tension rods X, Y carry on their ends a grooved wheel through which the

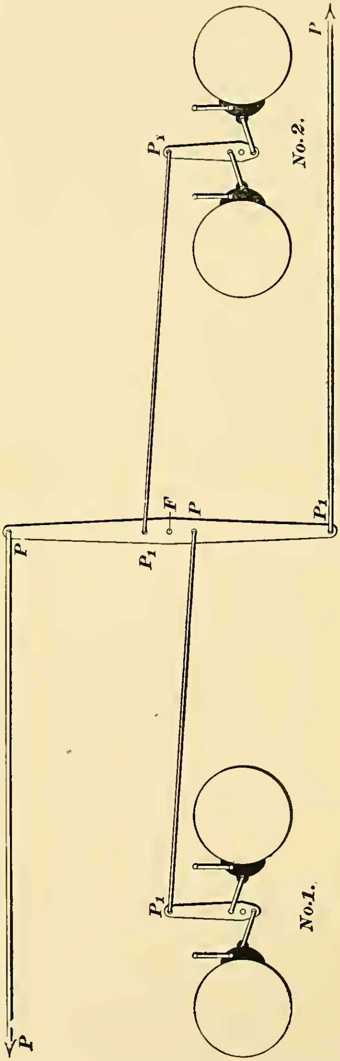


FIG. 63.

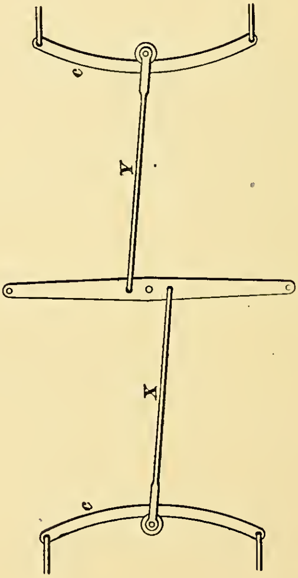


FIG. 64.

circle bars roll as the truck rotates, thereby preserving the position of the brake rigging.

66. Fig. 65 is a diagrammatic sketch of one-half the rigging used on a maximum-traction truck, where most of the weight is on the large wheels, so that most of the pressure must be applied to them. PWF is the truck brake lever whose fulcrum is fixed to the truck at F. A rod R runs from W to the brake beam on the larger wheel; at x the rod branches, the branch rod r returning to the brake beam on the smaller wheel. The branch rod is not continuous, but acts through a spring T, whose resistance can be regulated by means of a nut not shown in the diagram. The resisting force of spring T and its amount of compression are an exact measure of the pressure exerted on shoe S'.

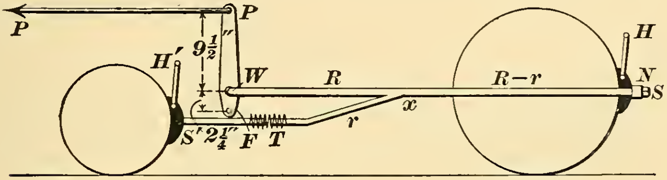


FIG. 65.

AIR BRAKES.

CLASSIFICATION.

67. Air brakes, as used on electric cars, may be divided into two classes, known as *straight air* and *automatic air*. In both classes, the brakes are set by allowing compressed air, stored in a reservoir, to expand into a *brake cylinder*, thus moving the piston and operating the brake levers. In a straight air equipment, the devices are such and are so arranged that the compressed air passes directly from the reservoir into the brake cylinder without passing through any automatic device. In an automatic air equipment, however, this is not so. Figs. 66 and 67 are diagrams illustrating the difference. In Fig. 66, when valve K_1 is open, pump P stores air in reservoir R, until gauge G shows the desired maximum pressure; K_1 is then closed. To apply the brake, valve K is opened; the air in R then expands into B, pushing on piston P_1 and shoving S against W. To release the brake, valve K is closed and K_2 opened, allowing the air in B to escape to the atmosphere, so that release springs s, s can pull the shoe from the wheel. Valves K and K_2 should never be opened at the same time, as this allows air to pass from R direct to the atmosphere, causing a great waste of air. In actual practice, valves K, K_1, and K_2 are operated by a single handle in such a way that wasteful connections cannot well be made.

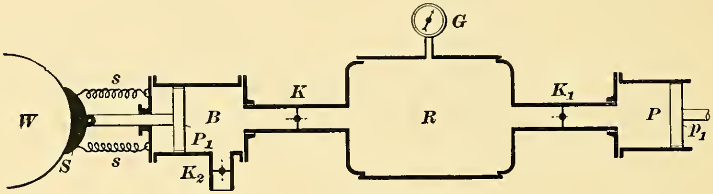


FIG. 66.

68. In Fig. 67, the main reservoir M is kept stored by a pump, both being on the engine or motor car. On each coach or trailer is an auxiliary reservoir R, a device called a triple valve, and a brake cylinder B. M, R, and B connect to the triple valve, as shown. The triple valve is automatic in action and has three duties to perform. It must make an opening between M and R, so that M can store air in R; it must connect R and B to apply the brake; and it must connect B to the atmosphere to release the brake. Piston p of the triple valve can move back and forth. Chamber A always carries main-reservoir pressure. The chamber on the left of piston p always carries auxiliary pressure. If the pressure in M exceeds that in R, p is forced to the left, as shown in the figure. In this position, air from M leaks through groove g and stores R until M and R are at the same pressure. To apply the brake, the pressure in the pipe connecting M

to the triple valve is reduced by letting out some of the air in it. This makes the pressure in chamber A less than that in

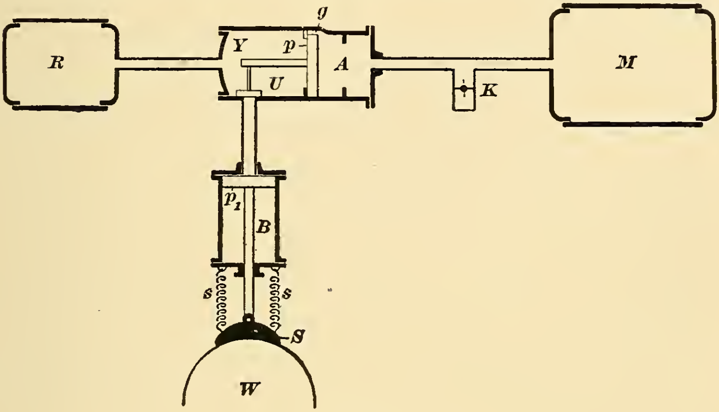


FIG. 67.

the auxiliary reservoir, thereby moving piston p to the right, uncovering the pipe leading to B, and opening up communication between R and B; this forces down piston p_1 and sets the brake. To release the brake, the motorman, by means of his operating valve, reestablishes communication between M and its connecting pipe, thereby raising the pressure in chamber A above that of the auxiliary reservoir R, so that p moves to the left and again closes communication between R and B. At the same time, by means of a valve, also operated by the stem of piston p, but not shown in the figure, communication is established between cylinder B and the atmosphere, thus letting the air out of the cylinder and allowing the release springs to release the brakes.

Automatic air brakes are used on long trains, because they allow the brakes to be set on all the cars at the same time. For ordinary trolley cars, where only single cars or a single car and trailer are operated, the straight air equipment is simpler and safer than the automatic air. The use of automatic air on electric cars is, therefore, confined principally to elevated and underground roads, where heavy trains of considerable length are operated.

69. Straight Air Equipment.—Fig. 68 shows the general arrangement of a Christensen straight air equipment as used with a trolley car and trailer. The outfit consists of an air compressor that is driven by a small geared motor; this compressor is usually well cased in and hung from the under side of the car. The motor that drives the compressor is controlled by an automatic governor that starts the motor when the pressure gets below a certain amount and stops it when the air has been compressed to the required pressure, usually about 60 pounds per square inch. The compressor stores the air in reservoir R, and from this reservoir it is allowed to flow into the brake cylinder by means of the operating valves at either end of the car. K, K are cut-out cocks in the reservoir pipe and K_1, K_1 are cut-out cocks in the brake-cylinder pipe. The cocks K_4, K_4 are for connecting on other cars, as indicated. The motor circuit of the compressor is controlled by two snap switches K_3, one at either end of the car, so that the motor may be cut out from either end or so that the motor may be controlled by hand in case anything goes wrong with the automatic governor. At each end of the car there is a gauge, provided usually with two hands; a red hand to indicate the reservoir pressure and a black hand to indicate the pressure in the brake cylinder.

70. The Brake Valve. — The brake valve, generally called the **engineer's valve,** is a device by means of which the motorman applies and releases the brake. It is located on the car platform between the hand-brake and the controller. The brake valve has three duties to perform. It is provided with a handle that controls the performance of these duties. In one position of the handle, the reservoir and the brake cylinder are connected, thereby setting the brakes. In a second position, the brake cylinder and the atmosphere are connected, thereby releasing the brakes. In a third position, all air passages are blanked so that there can be no movement of air in any direction.

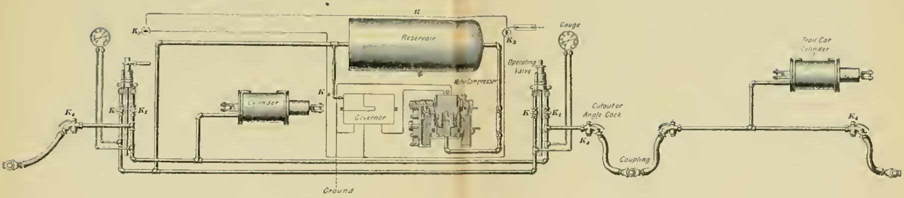

K_4
K
K_1
Cylinder
K_5
R
Reservoir
K_3
K_2
Governor
Motor Compressor
Operating Valve
Gauge
K
K_1
Cutout or Angle Cock
K_4
Coupling
Trail Car Cylinder
K_4
Ground

Fig. 68.

71. Fig. 69 shows the nature of the operations that the brake valve performs. B_1, E_1, and R_1 are three pipes leading from the brake cylinder, atmosphere, and reservoir, respectively, to the brake valve; on top of the valve body is a cap (*b*) that turns around b_1 as a center and has in it a slot *c c*. In the position shown in the diagram, the handle points front and the ports to which E_1 and R_1 lead are covered by the under side of the valve cap and do not, therefore, communicate with each other or with the port leading to pipe B_1. If, however, the valve handle is moved to the right, the slot in the cap connects ports B_1 and R_1 and air passes from the reservoir to the brake cylinder and shoves piston *p* to the dotted position p_1, thereby setting the brakes. If the cap handle is moved back to the vertical position, all the ports are again blocked and the air in the brake cylinder must remain there and keep the brakes set. By moving the valve handle to the left, ports B_1 and E_1 are connected, thereby allowing the air in the brake cylinder to escape to the atmosphere and permitting the release springs to pull the piston back to its normal position. The engineer's valves made by different manufacturers differ considerably in detail, but the operations that they perform are essentially those just outlined.

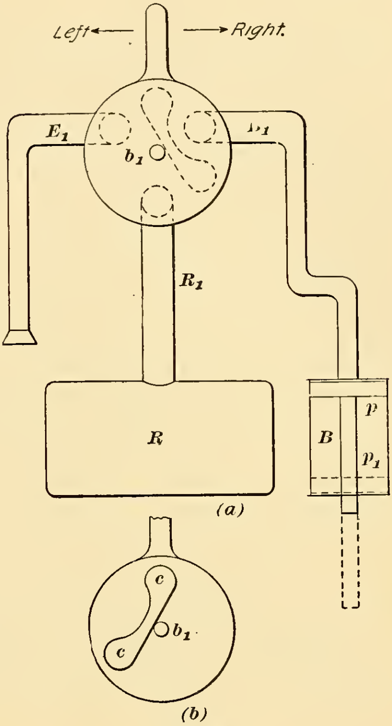


FIG. 69.

72. Positions.—Fig. 70 is a top view of the Christensen valve as it appears on a car. The dotted circles indicate the exhaust, reservoir, and brake-cylinder connections, as marked. There are five positions—namely, *lap*, *service stop*, *emergency stop*, *slow release* and *running*, *quick release*. The brake handle can be removed only on the *lap* position. In the *lap* position, the handle points towards the motorman; all ports are blanked so that none of the three pipes can communicate with each other. If there is any air in the brake cylinder, it is held there.

To make a **service stop**, the operating handle is moved to the right into the **service** position. In the service position, a small opening is created between the reservoir and brake cylinder, so that compressed air passes from the reservoir into the cylinder; as this opening is small, the flow of air is gradual and the degree to which the brakes are set depends on the length of time that the valve is allowed to rest in the service position. If in making a service application, the motorman finds that the car is going to stop too soon, he releases the brakes a little by letting a little air out of the brake cylinder; this is done by throwing the operating handle to the *slow-release position.*

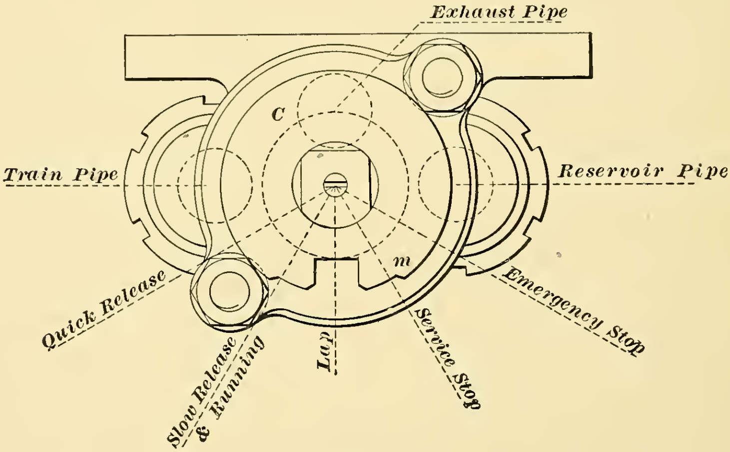


FIG. 70.

In the **slow-release** position a small opening is created between the brake cylinder and exhaust pipe, thereby letting some of the compressed air in the brake cylinder escape into the atmosphere; this lowers the pressure in the brake cylinder and tends to release the brakes. If the handle is left on the slow-release position too long, the brakes will release entirely.

When the valve handle is moved to the **full-release** position, the air in the brake cylinder escapes to the atmosphere in a single puff; this gives the release springs a chance to pull the brake piston, levers, and shoes to the release position.

If the operating handle is moved to the right as far as it will go, a full and unobstructed passage is opened between the reservoir and brake cylinder, thereby allowing the full reservoir pressure to act upon the brake piston and immediately setting the brakes with full force. This position is known as the **emergency** position.

THE GOVERNOR.

73. Wherever a motor-driven compressor is used, means must be provided for starting the compressor when the pressure in the reservoir becomes too low and for stopping it when the pressure reaches the value at which it is intended to operate the brake.

74. The Christensen Governor.—A top view of the automatic governor or "automatic" used on the Christensen air-brake equipment is shown in Fig. 71. *L* and *R* are electromagnets; *A A* is an armature or plunger that can slide back and forth between the magnets and carries an arm to which the finger *K* is fastened by means of the insulating block *I*. When an electric current is made to pass through the magnet *L*, the plunger or armature *A A* is pulled to the extreme left-hand position. Finger *K* makes contact with finger *K'*. When a current passes through the magnet *R*, the armature is pulled to the right and the motor circuit of which *K* and *K'* are a part is opened. *D* is a coil through which all current that goes to the motor must pass; this coil acts as a magnetic blow-out to extinguish the arc that forms between *K* and *K'* before it can burn or blister them and thereby impair their electrical contact.

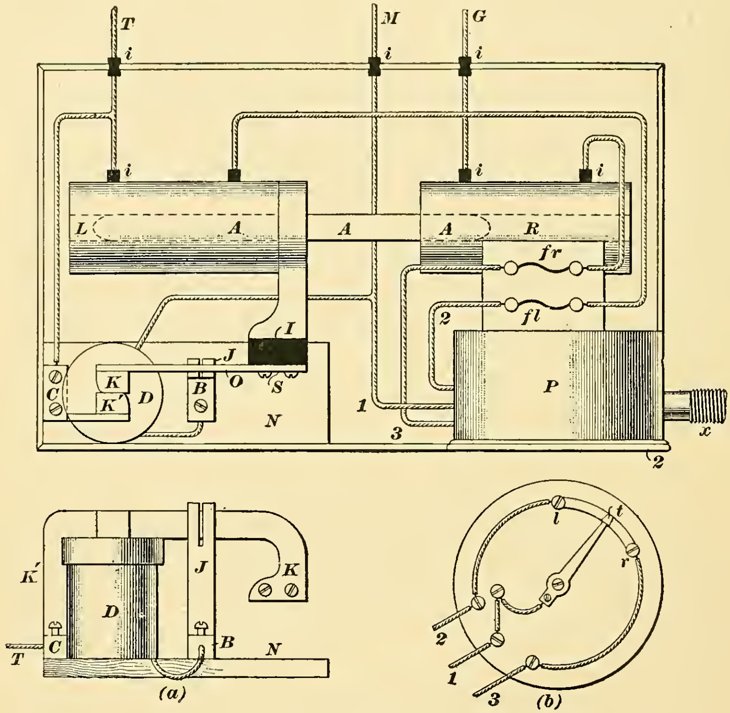


FIG. 71.

When fingers *K*, *K'* are pulled apart, the open circuit lies between terminals *C* and *B*. In other words, when the fingers *K* and *K'* touch each other, the current coming in on the trolley wire *T* takes the path *T–C–K'–K–J–B–D* through the blow-out coil and to the wire *M* that leads to the motor circuit.

75. *P* is the *regulator* that determines which of the two magnets *R* and *L* shall get current and these determine whether or not the compressor motor shall run, because when *L* gets a current, *K* and *K'* touch; but if *R* gets a current, they do not. *P* is a contact maker or circuit opener and closer, whose action is exactly the same as that of a pressure gauge. The hand of the gauge, instead of being used to indicate pressure on a scale, is made to carry on its end a little carbon knob *t*, Fig. 71 (*b*), that plays between contact buttons. These contact buttons are lettered *l* and *r*, because when *t* touches button *l*, magnet *L* gets a current; and when *t* touches *r*, magnet *R* gets current. Pipe connection *x* goes to the reservoir or to one of its pipes, as shown in Fig. 68; f_r, Fig. 71, is a fuse in circuit with magnet *R* and f_l is a fuse in circuit with magnet *L*. One end of fuse f_r leads to connection *3* in the rear of the regulator and from there to contact button *r*. The other end of the fuse goes to magnet *R*. One end of fuse f_l goes to post *2* on the rear of the regulator and thence to contact button *l*; the other end of the fuse goes to magnet *L*. The middle contact post *l* on the rear of the regulator connects to the hand that carries the carbon knob *t*, and since the hand moves, the connection is made by means of a very flexible wire. Post *l* also connects on the outside to the wire that runs from the blow-out coil *D* to the motor circuit. All shaded parts marked *I* or *i* are hard-rubber insulating parts. Wires *T*, *M*, and *G* are the main governor wires leading to the car trolley wire, the pump motor, and the car ground wire, respectively.

Fig. 72 is a diagram of the connections of the governor. The regulator hand *t*, Figs. 71 (*b*) and 72, is so adjusted that when there is no pressure in the reservoir, and therefore no force within the air lobe that operates it, a spring forces the carbon knob against contact post *l*. Suppose that there is no air in the reservoir and that it is necessary to start the pump to get up pressure; the carbon knob *t* touches the contact *l*. Current comes in at *T* to point *X*, Fig. 72; if magnet *L* was the last one to operate and the armature *A A* is, therefore, in its extreme left-hand position, as indicated in Fig. 71 (*a*), fingers *K* and *K'* make contact, thereby connecting points *B* and *C*, Fig. 72, so that the current splits at *X*;

part of it takes the path *X–C–B–D–Y–M–M′–W–Ground* and starts up the pump motor, and part of it takes the path *X–L–*f_l*–l–t–Y–M–M′–W–Ground* through the left-hand magnet coil *L*, exciting it. In this particular case, where the armature *A A* and the finger *K* are already at the extreme left-hand end of their travel, magnet *L* does not do anything. Suppose that at the time the pump switches were closed, armature *A A* happened to be so far to the right that fingers *K* and *K′* failed to touch each other. In this case, when the current gets to *X*, it cannot go through the pump motor and start the pump, because the circuit is open between *B* and *C*. But it does take the path through the left-hand magnet, which then pulls the armature *A A* to the left, causes *K* and *K′* to touch, and starts the pump. It is true, as can be seen in Fig. 72, that the current that passes through magnet *L* to pull *A A* over to the left also must pass through the pump motor to reach the ground; but on account of the resistance of magnet *L*, this current is too small to start the motor.

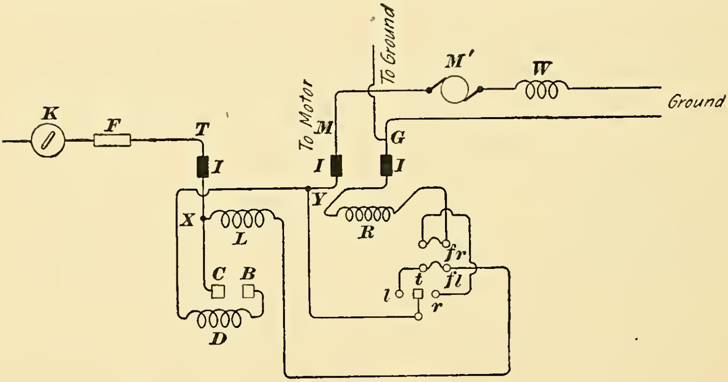


FIG. 72.

76. As the pressure in the regulator increases, due to an increase in the reservoir pressure, contact *t* is pulled away from contact post *l* and interrupts the flow of current through magnet *L*, Fig. 72. Armature *A A* still remains at the extreme left-hand end of its travel; contact fingers K, K' still touch each other; and the pump motor still works, for there is as yet no influence brought to bear to pull the armature to the right.

77. As the pressure in the reservoir increases, the carbon knob t moves slowly away from contact l towards contact r. As soon as it touches contact r, current from the trolley wire takes the path $T–X–C–B$ (remember that fingers K and K' on contact blocks C and B still touch each other) $D–Y–t–r–f_r–R–G$. Magnet R pulls armature A A, Fig. 71, quickly to the right, pulls fingers K and K' apart, and stops the pump motor. At the same time, since coil R gets its current from the motor-circuit trolley wire at point Y, which is on the negative side of the contact breaker K K', as soon as the circuit opens between K and K', magnet R can no longer get any current and can exert no pull on A A, which, however, lies there until a fall in the pressure causes the knob t to drop back on contact l, once more pulling A A to the left.

78. The Standard Air-Brake Governor.—The governor used by the Standard Air-Brake Company is somewhat different in principle from the Christensen governor just described. Fig. 73 is a general view of the device and Fig. 74 shows the electrical connections. In Fig. 73, S is a heavy spring that acts against the reservoir pressure in cylinder C to determine the position of lever L, which, by means of a connecting-rod, moves switch blade *14*, Fig. 74, in and out of contact jaws *13* and *15*. d is an iron-enclosed electromagnet that has

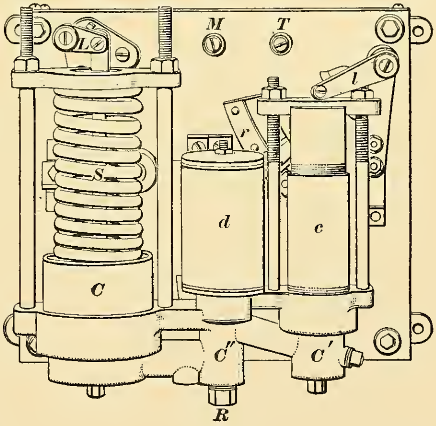


FIG. 73.

within it a plunger that is free to move down or up, according as *d* is excited or not. In chamber C'', Fig. 73, is a spring that pushes up on a cone-seated pin valve. Chamber C'' admits air to cylinder C' when the pin valve is in the proper position and cylinder *c* carries a piston whose stem operates lever *l* to move a contact arm over plates *r*, *r*, Fig. 74, thereby cutting resistance in or out of the motor circuit, as occasion may demand. The reservoir pipe is connected at fitting *R*, Fig. 73. The piston in cylinder *C* is pressed down by spring *S* and up by the reservoir pressure below it. Spring *S* is so designed that it can keep the piston down and switch *13–14–15*, Fig. 74, closed when the reservoir pressure acting against it is less than 50 pounds to the square inch. As soon as the reservoir pressure gets above 50 pounds, it begins to compress spring *S* and moves lever *L* counter-clockwise. Immediately a rod, also connecting lever *L* to the switch mechanism, starts to pull on this mechanism, which is so designed that it does not actually pull the switch out until the pressure reaches 60 pounds per square inch. The switch is pulled out by a spring that snaps it out to avoid any arcing. When the reservoir pressure is below 50 pounds, the piston in *C*, Fig. 73, is at the lower end of its travel and the switch is in, so that the pump motor runs and raises the pressure. As soon as the pressure gets above 50 pounds, it compresses the spring *S*, raises the lever, opens the switch, and stops the motor at 60 pounds.

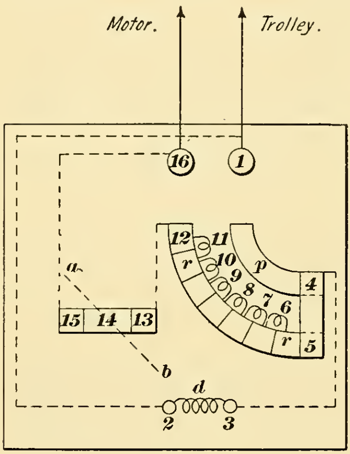


FIG. 74.

79. This arrangement alone would constitute a governor, for the pump is started when the pressure reaches normal value. But the Standard people do not approve of starting even a series motor at frequent intervals, by placing it dead across the line without any resistance in ahead of it.

80. With this governor, whenever the motor is started, a resistance is placed in series with it. As stated before, there is a spring in chamber C'', Fig. 73, that ordinarily presses up on a double-seated pin valve and closes all communication between chamber C' and the reservoir. A spring keeps the piston in cylinder c at the lower end of its travel when there is no air pressure admitted to chamber C' to force up the piston. In this position, lever l is down, as shown in Fig. 73, and contact arm *4–5*, Fig. 74, is in the position shown; all resistance is in.

81. The connections are shown in Fig. 74; post *1* takes the wire from the pump-motor snap switch and fuse box and is also connected to post *2*, to which one terminal of coil d also connects. Post *16* connects to one jaw of main switch *13–14–15*, and plate *12* of the series of resistance plates connects to the other jaw of the switch. When the switch is closed, as shown in the figure, the spring blade *14* connects jaws *13* and *15*; but when the switch is open, the blade takes the position indicated by the dotted line a b and no current can get from jaw *13* to jaw *15*. Post *3* connects to plate p. If switch *14* is closed, current comes in on post *1*, takes the path *1–2–3–4–5–6–7–8–9–10–11–12–13–14–15–16*, on through the pump motor to the ground. All resistance is cut in, as contact arm *4–5* is on the first plate, which position is caused by the piston in cylinder C being at the lower end of its travel, thereby pulling down the lever l, Fig. 73.

82. **Operation.**—Now, when the air in the reservoir is up to standard, spring S is somewhat compressed by the standard pressure under the piston on which it sets, switch *14* is open, and the pump is stopped; also, there is no air under the piston in cylinder c, because the spring in chamber C'' presses up on the pin valve and closes it. As soon as an application of the brakes or leakage causes the pressure in the reservoir to fall below 45 pounds per square inch, spring *S* pushes down the piston and stem and closes switch *14*, Fig. 74, allowing the pump motor to start.

Since resistance arm *4–5* is in the position shown in Fig. 74, all resistance is in and the starting current is small. The moment switch *14* closes, the starting current passes through coil *d* also and pulls down its core. The core presses down on top of the pin valve harder than the spring in chamber C'', Fig. 73, presses up; the result is that the valve is pushed off its seat, air is let into chamber C', which raises the piston and stem connections to lever *l*, moves contact arm *4–5* clockwise, until it gets to plate *12*, where all resistance is cut out and the pump motor runs at full speed. As soon as the reservoir pressure reaches standard value and switch *14*, Fig. 74, opens, magnet *d* becomes dead, the spring in chamber C'', Fig. 73, once more closes the inlet end of the pin valve, the compressed air in the cylinder *c* escapes to the atmosphere, and the piston stem, lever *l*, and resistance contact arm *4–5* resume their normal positions.

THE BRAKE CYLINDER.

83. Fig. 75 is a sectional view of a brake cylinder. *4* is the piston; *13*, the hollow piston stem; *8*, the release spring; *2*, the front head; *3*, the back head; *1*, the cylinder body; *12*, the head bolts; *11*, the bolts for securing the packing to the piston; and *6*, *7*, the forks through which pass bolts *15* and *16* and around which turn the brake levers.

84. Operation.—Fork *6* is stationary; fork *7* moves back and forth with the push rod *P*, which moves with the brake levers. When air is let in at the right-hand end of the cylinder, piston *4* is forced to the left, carrying with it push rod *P*, which moves the lever connected to pin *16* and sets the brakes. In moving to the left, piston *4* compresses spring *8*, so that when the brake valve is put on release position, letting all the air in the cylinder pass to atmosphere, spring *8* returns piston *4* and piston stem *13* to the normal position. Since fork *7* and push rod *P* are independent of piston stem *13*, the push rod must be returned to normal position by the release springs on the brake rigging. The object of having *P* and *13* independent of each other is so that when the hand-brake is used and push rod *P* must be pulled out, it will not be necessary to pull out *4* and *13* against the action of spring *8*. The travel of the brake piston should be kept within the limit prescribed by the brake company. After this limit is passed, the side pressure of the push rod *P* on the hollow stem *13* may be great enough to bend the rod or split the stem.

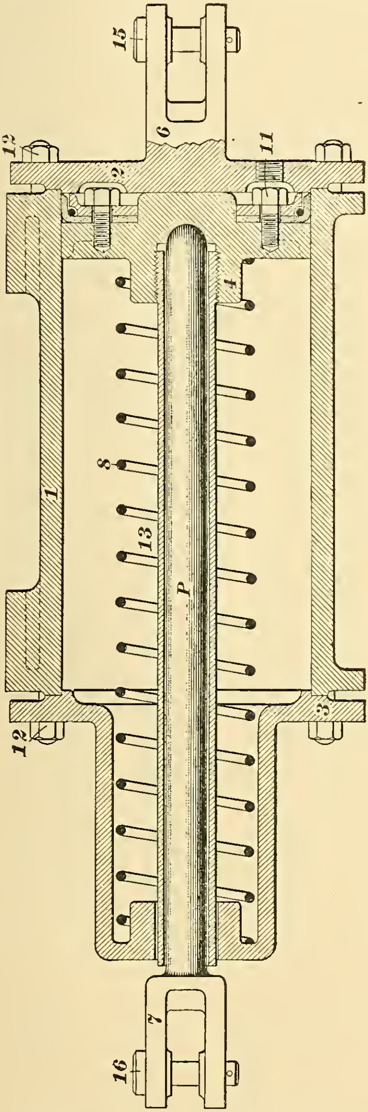


Fig. 75.

LEVER SYSTEM.

85. Fig. 76 shows a system of air-brake levers recommended by the Christensen Company. The diameter of the brake piston is in this case 6 inches and its area, in round numbers, is 28 square inches. Supposing that the reservoir has a pressure of 60 pounds per square inch and that full pressure is let into the cylinder, the total pressure on the piston that shoves on

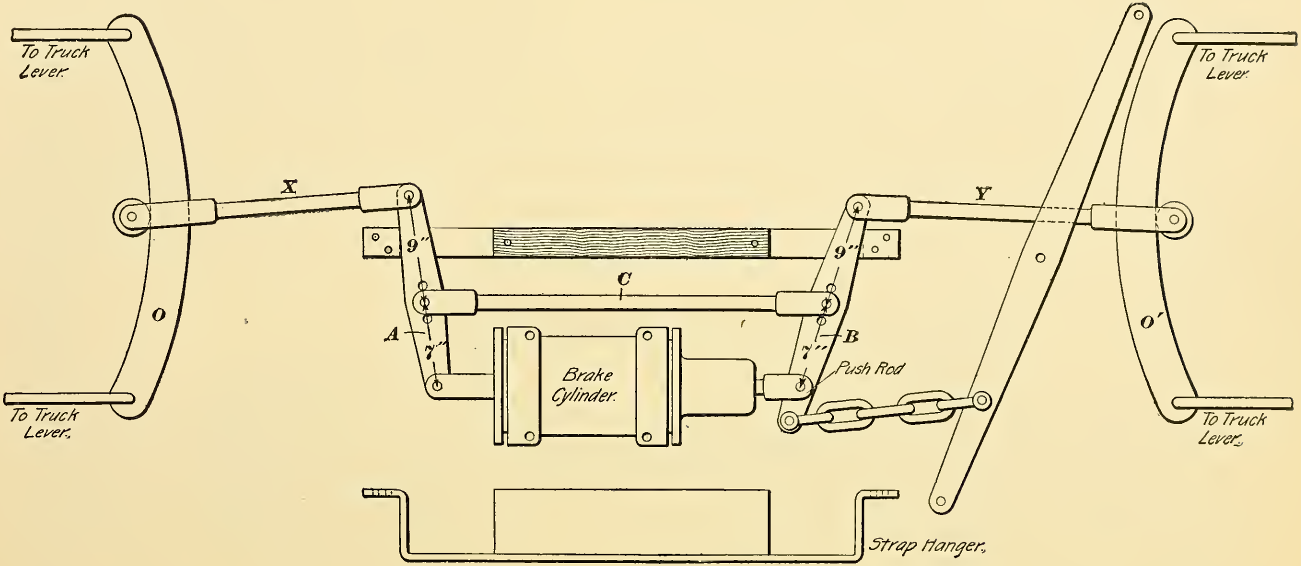

To Truck Lever.
To Truck Lever.
O
X
9"
A
7"
C
Brake Cylinder.
Y
9"
B
7"
Push Rod
O′
To Truck Lever.
To Truck Lever.
Strap Hanger.

FIG. 76.

the push rod and sets the brake is 28 × 60 = 1,680 pounds. *A* and *B* are the two levers that apply the brake; one end of *A* is fixed to the back head of the cylinder, the other end attaches to the tension rod *X*. One end of *B* connects with the push rod and the other end with the tension rod *Y*. Levers *A* and *B* are also connected through the tension rod *C*. Air admitted to the cylinder causes the push rod to move to the right, carrying with it the lower end of lever *B*. Using rod *C* as a fulcrum, lever *B* pulls on rod *Y*. Using rod *Y* as a fulcrum, lever *B* pulls on rod *C*.

When the hand-brake is used, the push rod is pulled in and out of the hollow piston that holds it. It will be noticed that the air brake and hand-brake operate in the same direction, so that if the air brake were applied with the hand-brake already partially set, there could be no danger to the motorman or the brake rigging.

THE ELECTRIC BRAKE.

86. Electric brakes are operated by making the motors act as generators to supply the necessary current. They may thus be operated no matter whether the trolley wheel is on the wire or not and do not take any additional current from the power station. In order that the brakes may take hold, the car must be in motion; hence, electric brakes cannot hold a car on a grade, although they may bring it nearly to a standstill. To hold the car, the hand-brakes must be applied. The electric brake that has so far been most largely used is that manufactured by the General Electric Company; we will, therefore, describe it briefly.

87. Fig. 77 shows the brake used on a motor car. It consists of a cast-iron ring split horizontally and held together, as shown, by bolts. As indicated by the dotted lines, there are magnetizing coils *C*, *C* in each half of the ring. Each coil consists of 32 turns of No. 8 wire. The sectional view shows how the coils are embedded in the iron and held in place by pouring in lead *P*, *P*, the insulation of the coil being protected from the hot lead by a thin layer of asbestos, not shown in the figure. The wearing plate *W* is in two pieces, one on each half of the brake ring and held on by capscrews. The two magnetizing coils are in series, connection with the car wire being made by means of leads *L*.

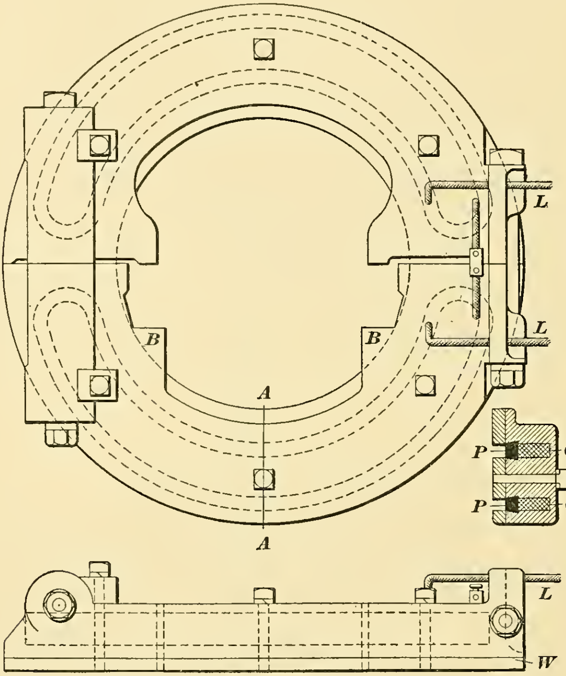


FIG. 77.

88. Fig. 78 shows the manner of *support*. The motor-bearing cap *C* has two projecting horns *A*, one behind and the other in front of the car axle. Lugs *B*, Fig. 77, of the brake ring rest on these horns, and thus the brake is held close to the disk *S* that turns with the axle. Setscrew *M* is used to take up the wear in the disk and ring. The ring has $\frac{1}{32}$ inch end play, but cannot rotate at all; hence, when it is magnetized, it draws itself over, clutches disk *S*, and tends to prevent its turning, thereby acting as a brake. Both the disk and ring are provided with wearing plates *W*.

So far as the motorman is concerned, the addition of the brake attachment does not add complications to either his cares or operations. On the main controller drum is a neutral position; on one side of this position are the power contact tips and on the other the brake contact tips. To start the car, the controller handle is operated as usual; to throw the current "off," preparatory to making a stop, the handle is thrown to the off-position, as usual; to apply the electric brake, the handle is simply kept moving past the off-position. To release the brake, the handle is returned to the off-position.

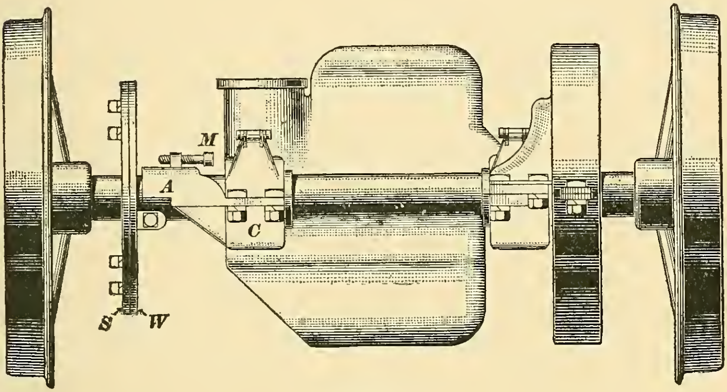


FIG. 78.

THE CONTROLLER.

89. The Main Drum.—The main drum is shown in the left-hand upper corner of Fig. 79. This drawing shows the connections for electric brakes used with a four-motor equipment with the B6 controller. There are 11 rows of contact tips. All tips that are marked with the same letter are metallically connected and the subjoined figure indicates the position on which the tip comes into action For example, PA_1 indicates that the tip is a power tip, that it is a part of the A drum casting, and that it comes into action on the first power position.' PA_{10} is a power tip on the A casting and comes into action on the tenth power position. BA_4 is a brake tip of the A casting and comes into action on the fourth brake position. All the tips marked A are connected; if the A is preceded by a P, it is used in applying the power to start the car ; if it is preceded by a B, it is used on a brake position to stop the car. Thus it will be seen that some of the castings have tips, such as PA_1 and BA_2, etc., in common to applications of both the power and the brake, but are not in use at the same time. On the left of the main drum are shown the 11 main-drum fingers, T, R_7, R_6, R_5, R_4, R_2, B, R_7, *8*, E_1, and G. On the right of the main drum, these fingers are reproduced, not because there are actually two rows of fingers, but simply to make it easier to trace current paths; therefore, no wires are run to these fingers. When the car is being started, the student will imagine the main-drum contacts to move towards the left-hand row of fingers; when it is stopped, the drum moves towards the right-hand row. Thus on the first power notch, fingers T, R_2, B, and *8* make contact on the left-hand end of the drum; on the first brake notch, fingers B, E_1, and G touch the right-hand end of the drum. The row of enclosed numbers, beginning at *1* on the left and running up to *12*, shows the positions used in applying the power; the row beginning at *1* on the right shows the positions used in applying the brake. There is, therefore, a portion of the main drum, between power position *12* and brake position *6*, not touched by the fingers at all. This untraversed space is dictated by the width of the lug on the controller top; when the controller handle gets to the full multiple position, the twelfth position, one side of the lug stops it; when it gets to the last brake notch, the sixth position, the other side of the lug stops it.

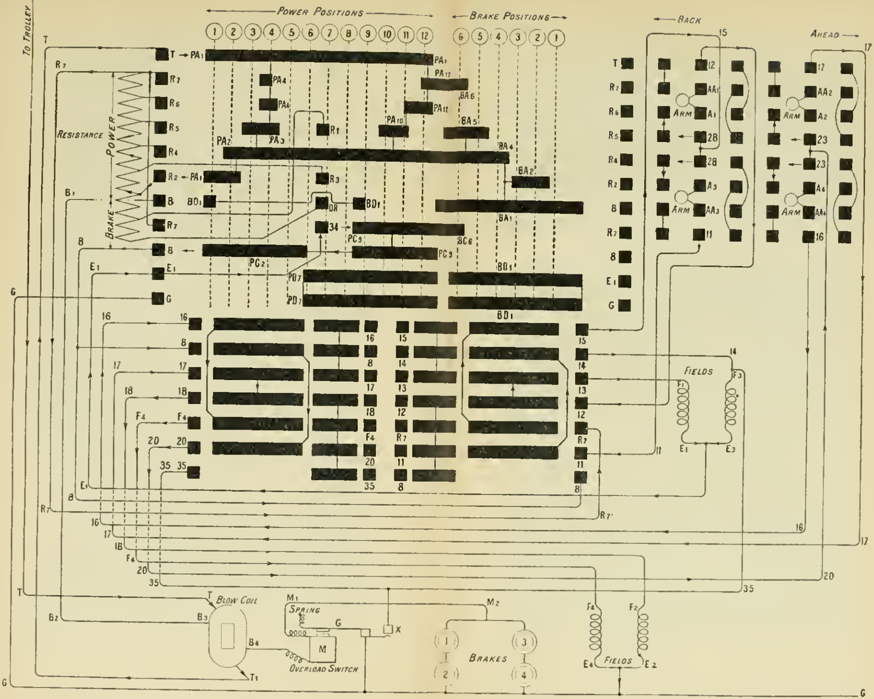

To Trolley
Power Positions
1 2 3 4 5 6 7 8 9 10 11 12
Brake Positions
6 5 4 3 2 1
Back
Ahead
Resistance
Power
Brake
T
R7
R6
R5
R4
R2
B
E1
G
PA1
PA2
PA3
PA4
PA10
PA11
PA12
BA1
BA2
BA4
BA5
BA6
BD1
BC6
PC2
PC3
PC9
PD7
OR
34
R1
R3
B1
B2
B3
B4
T1
Arm
AA1
AA2
AA3
AA4
A1
A2
A3
A4
12
28
23
11
15
16
17
18
F4
20
35
14
13
8
Fields
F1
F2
F3
F4
E1
E2
E3
E4
Blow Coil
Spring
Overload Switch
M
M1
M2
X
Brakes
1 2 3 4

Fig. 70

90. Auxiliary Fingers.—In the center of the space that the drawing devotes to the power part of the main drum are four fingers R_1, R_3, DR, and *34*. These fingers being independent of the main-drum fingers proper and not being in line with them vertically, but being in line with them horizontally, can make contact with one part of a drum tip, while one of the drum fingers proper is resting on another part of the same tip. For example, on the first power notch, main finger B makes contact with tip BD_1 at the same time that auxiliary finger DR makes contact with its mate BD_1. The object and action of these auxiliary fingers will be taken up later.

91. The Reverse Drums.—The *reverse drum proper*, which is used to reverse the direction of motion of the car, is in the top right-hand corner of the drawing. This reverse drum is the one found on all up-to-date controllers, whether they control electric brakes or not, and interlocks with the main drum in the usual way. On this controller, there are two rows of reverse fingers, each row handling two motors. At the bottom of the controller development, under the main drum, are shown two auxiliary drums, which we will call the *generator reverse drums*, because their object is to keep the armatures of the motors of such polarity that they are connected to generate when the electric-brake connections are in use. The drum on the left is coupled directly to the shaft of the main drum, and so turns in the same direction as and with the main drum; the reverser drum on the right gets its motion through the agency of a gear on the main-drum shaft, and so turns in a direction opposite to that of its mate and the main drum; both of the generator reverse drums, then, are operated by the main drum, without extra precaution on the part of the motorman, and are operated in opposite directions. Each of the generator reverse drums has a neutral position and a row of fingers of its own. Each row of fingers is reproduced on the drawing to facilitate tracing out current paths. Under normal conditions, when the car is going "ahead" and the brake is "off," the fingers *16*, *8*, *17*, *18*, F_4, *20*, on the left-hand drum, and fingers *15*, *14*, *13*, *12*, R_7, *11*, on the right-hand drum, rest on the long strip portions of their respective drums and remain so connected throughout the power positions of the main drum. The current from the trolley passes through the armatures of the car motors in a certain direction.

92. When the motorman throws his power handle to the off-position and continues it in this direction to the first brake notch, the fingers of the two generator reverse drums leave the long strip portions of their drums, pass to the short strip portions, and remain there throughout the six brake positions, thereby so connecting the motor armatures that they can generate.

93. Power Positions.—The power positions are indicated by the row of figures from *1* to *12*. On the first position, fingers T, R_2, *8*, *34*, B, and DR make contact (we will not consider B and DR for the present) on the main drum; all the fingers on the lower drums make contact, excepting *35* and *8*; the reverse switch is "ahead." The current path is through trolley–T–blow coil T_1–finger $T-PA_1-PA_1-R_2$ through the resistance coil to $R_7-R_7-R_7-R_7-R_7$ to finger *15* on the right-hand generator reverser–$28\left\langle\begin{matrix}A_1-AA_1-12-12-13-F_1-E_1\\A_3-AA_3-11-11-11-14-14-F_3-E_3\end{matrix}\right\rangle E_1-E_1-E_1-34-PC_9-PC_9-PC_2-8-8-8-20-20-20-20-23\left\langle\begin{matrix}A_2-AA_2-17-17-17-17-17-17-18-18-18-F_2-E_2\\A_4-AA_4-16-16-16-16-16-F_4-F_4-F_4-F_4-E_4\end{matrix}\right\rangle G$. The current path on the first notch is indicated by the arrowheads. It starts at the trolley; when it gets to reverse finger *28*, it splits, the current dividing between the No. 1 and No. 3 motors; the two currents reunite and flow as one to finger *23*, where they split again through the Nos. 2 and 4 motors, reuniting at E_2 or G, the ground wire. On the second position, the current path is the same except that finger R_4 cuts out two sections of resistance. On the third notch, R_5 cuts out another section, and on the fourth notch the remaining sections are cut out by finger R_7 and T making direct connection through tips PA_4 and PA_1. Upon all the positions just considered, the motors are in series-parallel.

94. Brake Positions.—To operate the brake, the handle is moved backwards from the off-position. To follow the combinations, it is easier to conceive of the main-drum tips moving towards the row of fingers reproduced on the right. It is also simpler to imagine the short tips of the two generator reverse drums to move towards the row of fingers nearest to them, as these two auxiliary drums turn in opposite directions. When the controller drum is moved backwards one notch, all the auxiliary drum fingers engage the tips under the word "brake" and continue to do so throughout the brake positions of the main drum. Main-drum fingers E_1 and G connect through tip BD_1; fingers B and R_1 connect through tips PA_3, BA_4, and BA_1. It will be noticed that finger B is the same distance from tip BA_1 that finger R_1 is from tip PA_3, so that when all the tips move to the right, those two fingers engage their respective tips at the same time. When the generator reverse-drum fingers pass from the long drum tips to the short ones, the armature connections of all the motors are reversed, thereby connecting the motors to act as generators. Consider armatures Nos. 1 and 3; while the long strips on the right-hand drum are in action, R_7 connects through *15* and reverse fingers *28* to A_1 and A_3, while AA_1 and AA_3 connect by way of *12* and *11* to fingers *13* and *14*. When the short strips are in action, A_1 and A_3 connect to *13* and *14* and AA_1, AA_3 to R_7.

95. Starting at finger *15* at the top of the right-hand reverser drum, we will trace a path to ground in both directions. To the right, the path is $15-\left\langle\begin{matrix}28-A_1-AA_1-12-12-R_7\\28-A_3-AA_3-11-11-11-R_7\end{matrix}\right\rangle-R_7$; $R_7-R_7-R_7-R_7-R_1-PA_3-PA_2-BA_4-BA_1-B-B_1-B_2-B_3-B_4-M-M_1-M_2$–brakes—to the ground at G. To the left from finger *15*, the path is $15-\left\langle\begin{matrix}14-14-F_3-E_3-E_1-E_1-E_1-E_1-BD_1-G\\13-13-F_1-E_1-E_1-E_1-E_1-BD_1-G\end{matrix}\right\rangle-G$. The No. 2 and No. 4 motors have one end of their field grounded at E_4 and E_2. Tracing the circuit back, the double path is $G-\left\langle\begin{array}{l}E_2-F_2-18-18-18\\E_4-F_4-F_4-F_4-F_4\end{array}\right\rangle-20-20-20-20-\left\langle\begin{array}{l}23-A_2-A\,A_2-\\23-A_4-A\,A_4-\end{array}\right.$ $\left.\begin{array}{l}17-17-17-17-17-17\\16-16-16-16-16\end{array}\right\rangle-8-8-8-R_7-R_7-R_7-R_7-R_7-R_1-P\,A_3-P\,A_2-$ $B\,A_4-B\,A_1-B-B_1-B_2-B_3-B_4-M-M_1-M_2$-brakes-$G$. All four motors have both ends grounded, and are therefore in multiple. No change is made after the first brake notch, except that resistance is cut out successively by fingers R_2, R_4, R_6, and R_7.

96. Fig. 80 is a simple sketch showing the connections of the motors, plugs, blow coil, overload switch, and brakes. The action of the overload switch is as follows: The magnet coil carries the braking current of all the motors; if this current exceeds a certain predecided value, magnet M pulls

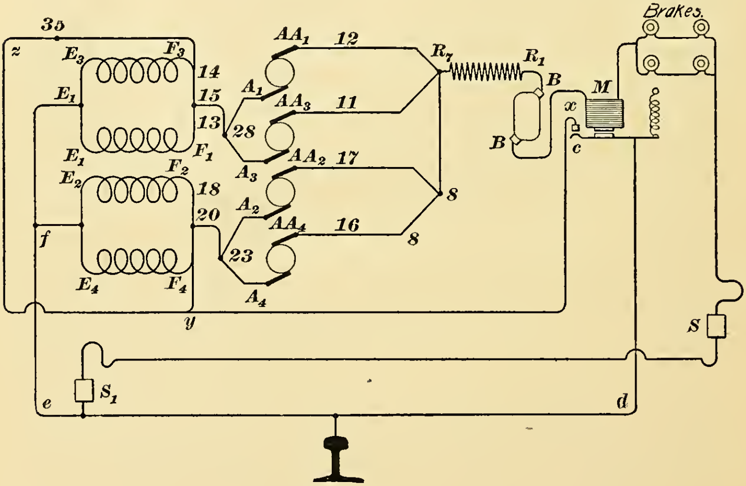


FIG. 80.

on its armature, thereby causing contacts c and x to touch, bringing together wires $x\,y\,z$ and $c\,d\,e\,f$; wire $x\,y\,z$ connects to one end of all the motor fields and wire $c\,d\,e\,f$ to the other end, so that when they touch, the motor fields are all short-circuited, depriving the motors of their ability to generate. As soon as this happens, magnet M releases, opening the short circuit and allowing the fields to build up again.

97. Releasing Brakes.—Full release of the brakes is accomplished by passing a demagnetizing trolley current through the brake coils. This operation is performed through the agency of finger DR and tips BD_1, Fig. 79. The resistance between fingers DR and R_1 is called the *demagnetizing* resistance, because it limits the strength of the demagnetizing current. The resistance is about 60 ohms. The demagnetizing current need be but very small, as the demagnetizing effect is helped considerably by the vibration incidental to the starting of the car. On the first power position, finger B engages one BD_1 tip and finger DR the other, so that on this position current from the trolley wire takes path: trolley–T–T–T_1–T–T–PA_1–PA_1 to finger R_2; here the current splits, part taking the path through the *power* part of the resistance to R_7 and thence to the motors, and part taking the path through the brake part of the resistance to finger DR, thence through path DR–BD_1–BD_1–B–B_1–B_2, etc. to the brakes. This trolley current passes around the brake coils in the opposite direction to what the braking current passed and so destroys the residual magnetism sufficiently to release the brakes.

98. An Exceptional Condition.—In ordinary applications of the brake, it is, of course, only necessary to throw off the power and to continue in that direction to the brake notches, the generator reverse drums tending to the reversal of connections ordinarily accomplished with the reverse switch proper on cars not equipped with electric brakes. In case, however, a car is ascending a hill and the blowing of a fuse causes it to start to roll backwards, the *direction* of *rotation* of the armatures has been reversed, so that their connections need not be; but the act of putting the power handle on a brake notch *has reversed* the connections. With the direction of rotation and armature connections *both* reversed, the motors *cannot* generate. Under such a condition, then, throw the reverse switch proper before putting the controller handle on a brake notch.

WESTINGHOUSE ELECTRIC BRAKE.

99. The Westinghouse electric brake also makes use of the generator action of the motors; but the brake itself differs considerably from the General Electric brake. The Westinghouse brake acts on the regular brake shoes and in addition also operates a pair of shoes that press on the track between the truck wheels. Fig. 81 shows the general arrangement of the brake. *a*, *a'* are the track shoes and *b*, *b'* the regular brake shoes. When not in use, the brake hangs suspended by springs *d*, *d'* a short distance from the rail; *c* is the magnetizing coil supplied with current from the motors running for the time being as generators. When current is sent through *c*, the shoes are pulled down against the track.

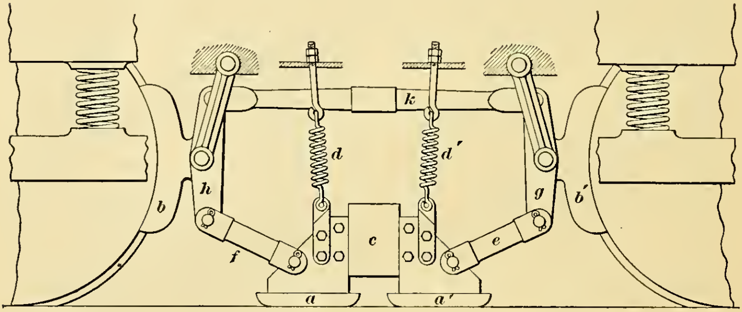


FIG. 81.

At the same time, the drag caused by shoes *a*, *a'* causes the regular brake shoes to be pressed against the wheels through the agency of the levers *e*, *k*, *h*, *f*, thus exerting a powerful braking action.

In the Westinghouse electric-brake system, the connections are arranged so that either the regular car starting resistance or the electric car heaters may be used as the controlling resistance for the brakes. By using the heaters in winter for the brake controlling resistance, a considerable saving is effected, because the current for the heaters is then supplied without drawing on the power station. In other words, heat is used that would otherwise be wasted.

THE MULTIPLE-UNIT SYSTEM.

100. The multiple-unit system is not intended for ordinary street-railway service, but is intended for the operation of trains ordinarily handled by steam engines. A single car with its full equipment for heat, light, brakes, and motive power constitutes a single unit; several such units coupled together into a train, with the proper provision made so that the motors on all the cars can be operated simultaneously from the platform of any car, constitute a multiple-unit train.

101. Suppose we take three ordinary surface trolley cars completely equipped, and that instead of running the car wires from controller to controller on each car and letting them end there, we run the wires from end to end, tapping off to each controller and putting suitable couplers on the ends, as indicated in Fig. 82, so that the car wires on one car can be made continuous with those on the car next to it; then we will have a three-car train. The main-current motor wires will run from one end of the train to the other, irrespective of the length of the train; the train can take the current from one trolley pole or from all the poles at once, and it can be operated from any one controller on any car, whether it is in the middle or on the end. Every car will do its own share of the work, so that the whole train will start, run, and stop as quickly as a single car. This will

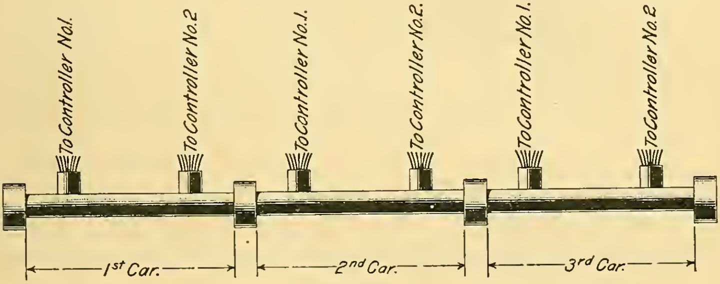


FIG. 82.

be a **multiple-unit system**; but there are several strong objections to the adoption of such a system. In the first place, there would be continual trouble with any single controller that would be called on to handle the current of more than two cars. Next, the car wiring would have to be extra heavy, as the wires on the end car, if the train were to be operated from that car, would have to carry the current of all the cars. Again, it would be almost impossible to devise a practicable coupler that would handle such heavy currents without giving continual trouble. Finally, in case of complications arising due to short circuits or grounds on the car wires of any car, the cut-out device that would meet all conditions would have to be very elaborate. These objections have been met and almost entirely overcome by the three multiple-unit systems now on the market. The essential feature of all these systems is that each car is a self-contained unit as far as the main-motor circuit is concerned.

102. On all the systems there is placed upon each platform of every motor car a small controller, called the *master controller*. In no case does this master controller take up over a cubic foot of space. Every car has what is called a train line; the wires running to the master controllers are done up in a small cable provided with couplers on the ends, just as shown in Fig. 82. The wires themselves and the currents that they carry are small, so that none of the troubles incidental to arcing, heating, or burning are encountered. When the train is made up, the train line extends from one end to the other, connecting all the master controllers and the mechanisms that they operate, so that all the main-circuit controllers and hence motors can be operated from any master controller on the train. It must be understood that the master-controller circuit is entirely distinct from the main-motor circuit and is just as free from liability to troubles as an ordinary lamp circuit. The master controller has a series and a multiple position, and it can be seen that it is extremely important that the main-controller operating devices should respond to the notches of the master controller with precision; for if the main-motor controllers should feed up at different rates, a condition might arise where the motors on some cars would be in series and those on other cars in multiple, thus producing a very bad state of affairs. This feature is taken care of by a synchronizing device that not only makes the main-motor controllers notch at the same rate, but also makes the cylinders notch with precision and with a springy centralizing motion that prevents the hanging of an arc.

Every car is provided with an electromagnetic throttle that stops the pilot motor or other device that runs the main-motor controller should the current for any reason exceed a predetermined value, based on the capacity of the motors, the traction of the wheels, and the rate of acceleration desired. The whole equipment is so balanced that the proper acceleration falls within the limit imposed by setting the throttles to work just below the slipping point of the wheels when the car runs light. The throttle makes it practically an impossibility for a motorman to abuse the motors, even should he handle the master controller recklessly. The main controllers can be put under the car, on the platform, under the hood, or inside the car under the seats, if there is room for them.

103. Air Brakes on Multiple-Unit Cars.—Each car has its own air-braking outfit, consisting of a motor-compressor governor, triple valve, tanks, etc., so that if called upon to run alone, it can do so. Simultaneous starting and stopping of the air pumps is accomplished by means of a balance wire running the length of the train and connecting all the junctions of the motor compressors and their governors. Each of the governors is actuated by pressure from the main reservoir, and all these are connected by a balance pipe running the length of the train, so that all compressors are started or stopped by the weakest governor in the lot. The compressor on any car can be cut out, its tank being kept filled by the others. It can be seen that each car is absolutely an independent unit. The advantages of the system in heavy train work are many, and it is destined to fill a large field in the near future. Trains can be split up, shifted, and housed without the aid of any outside source. It also has the advantage that instead of lengthening the intervals between trains in the quiet hours of the day, the time table can be kept the same and the trains themselves shortened, even down to running single cars. Where every car is a motor car, the starts are much smoother, there is no bumping or jerking, as each car starts itself and there is never much tension or compression on the drawbars, and the trains are not apt to break in two.

104. The multiple-unit system has, so far, been used mostly on elevated roads. The outfit is necessarily somewhat complicated, but notwithstanding this fact, it has given good service. The above description will give the student a general idea as to how the system is operated. The details of the different devices and connections are beyond the scope of this Course.

INDEX

NOTE.—All items in this index refer first to the section (see the Preface) and then to the page of the section. Thus, "Alternators 10 56" means that alternators will be found on page 56 of section 10.