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

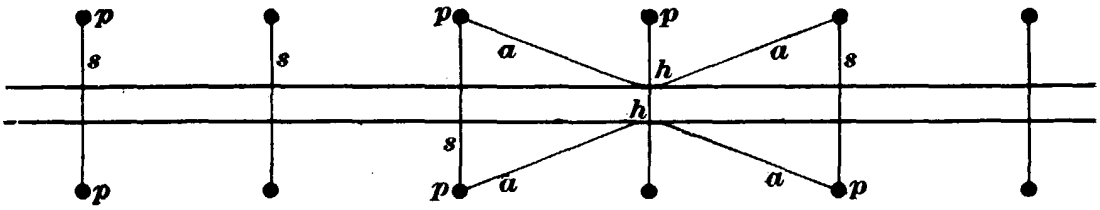

FIG. 1.

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

§ 22

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

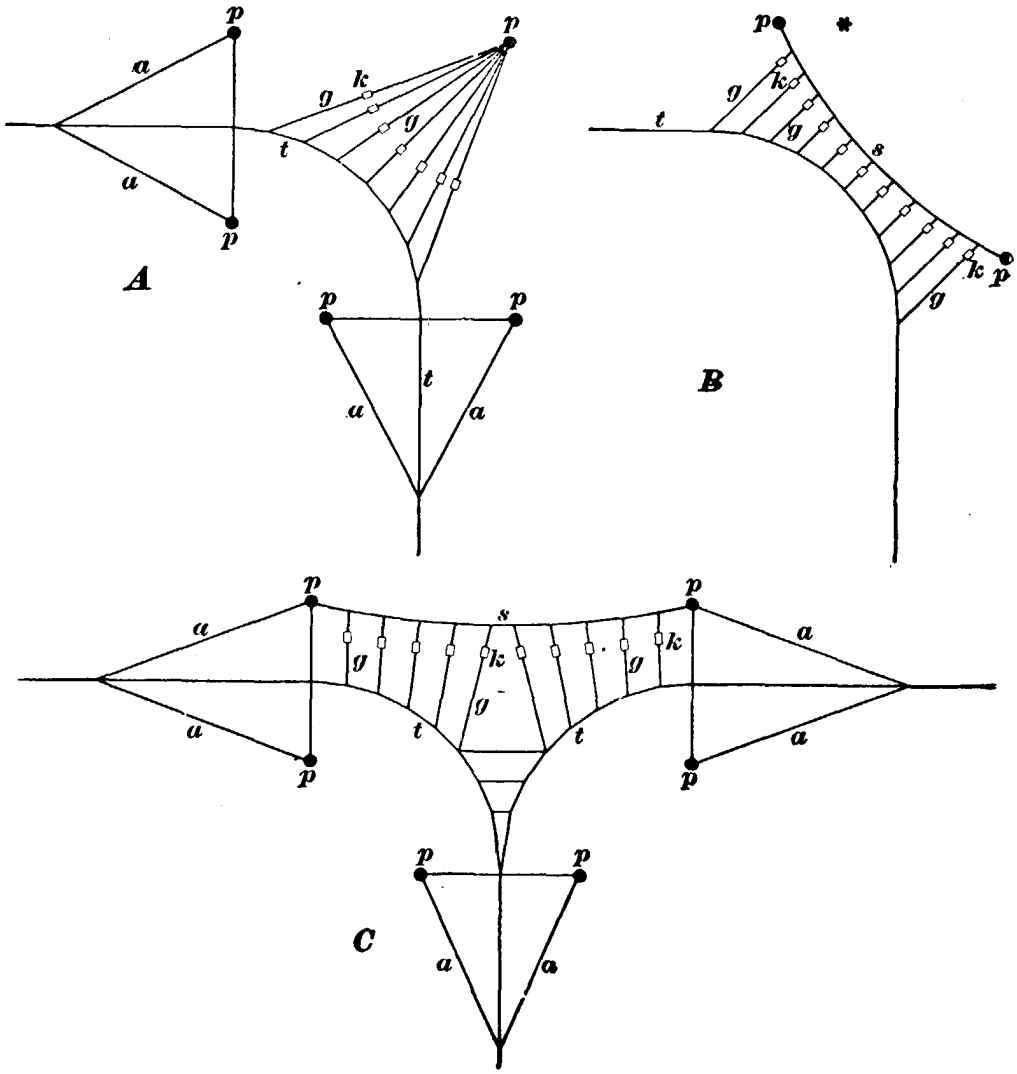

FIG. 2.

the arrangement of guy wires *g* attached to the trolley wire *t* when a single pole is used. Strain insulators are usually

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:

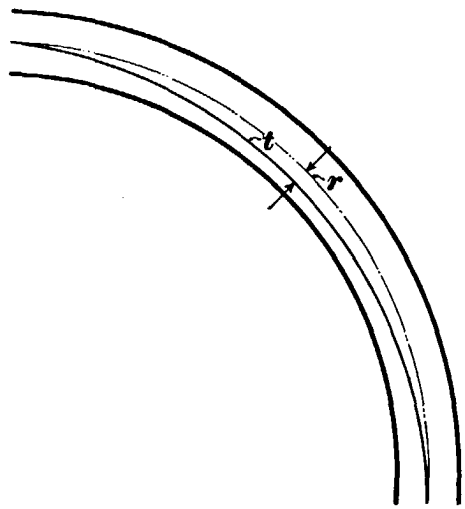

FIG. 3.

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.

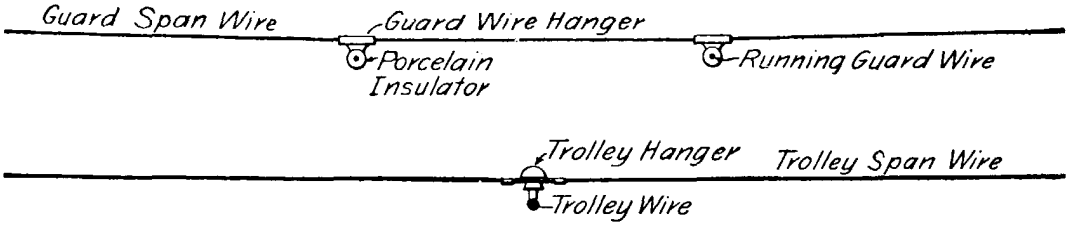

FIG. 4.

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

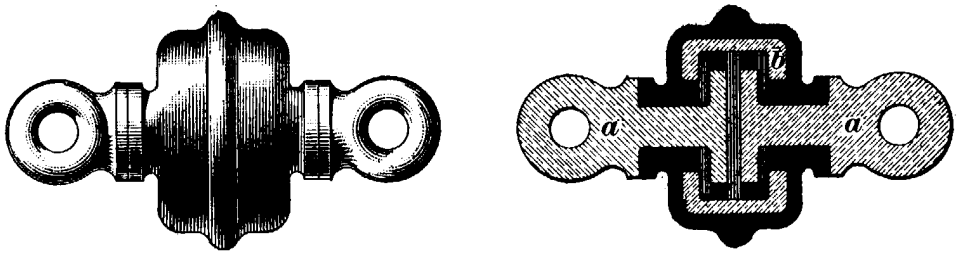

FIG. 5.

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

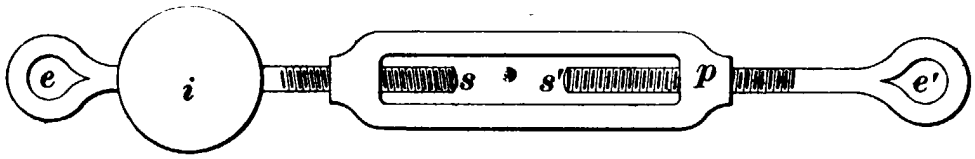

FIG. 6.

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.

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

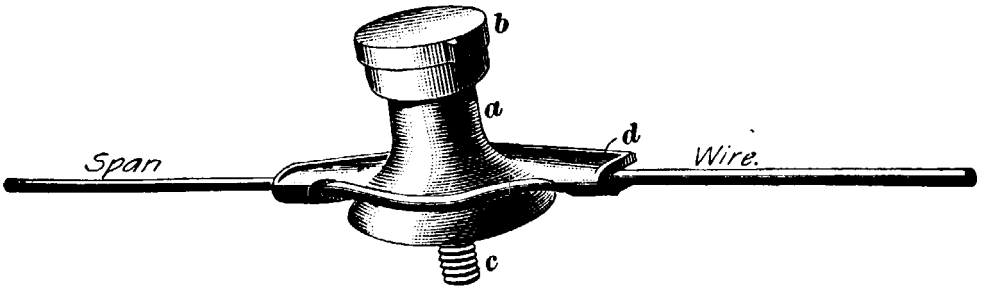

FIG. 7.

is covered by a metal cap *b*. The ear to which the trolley wire is fastened screws on *c*.

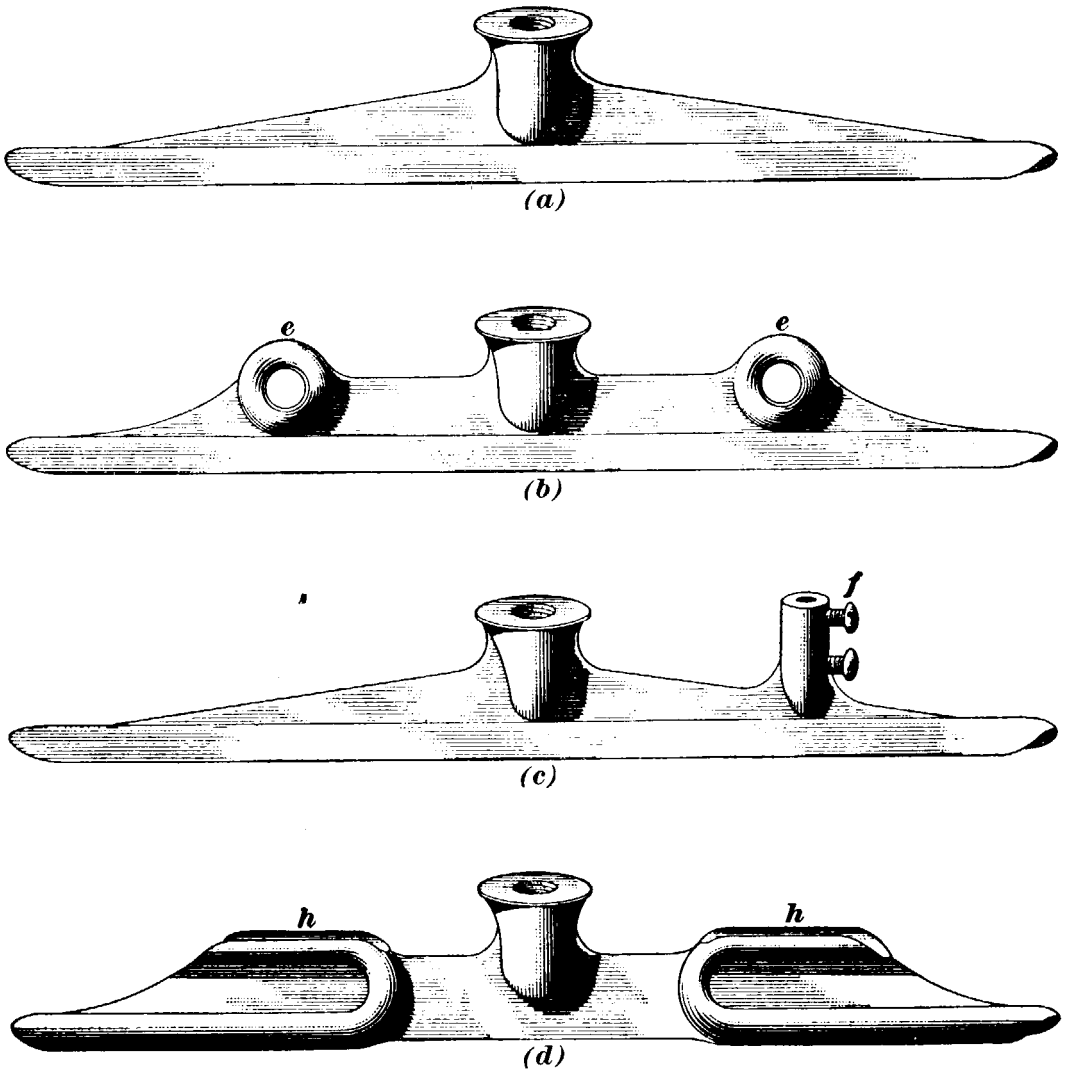

FIG. 8.

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.

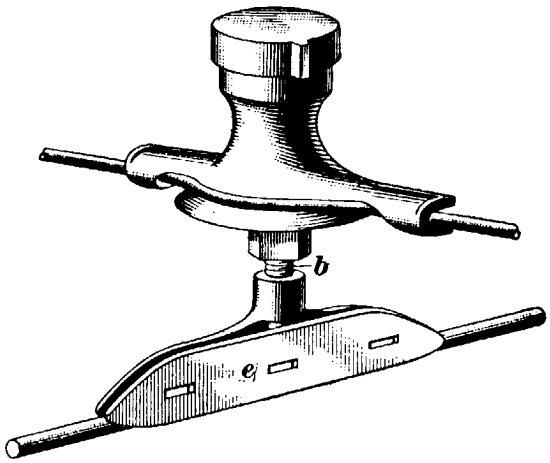

FIG. 9.

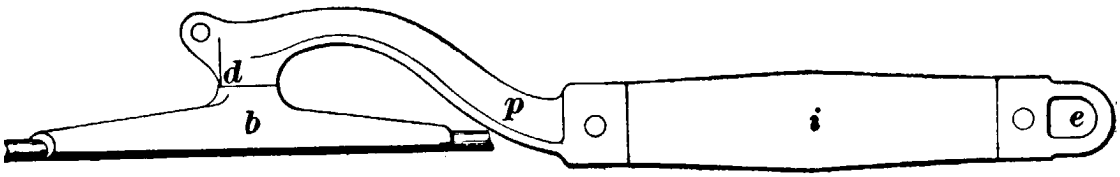

FIG. 10.

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 *c*, which

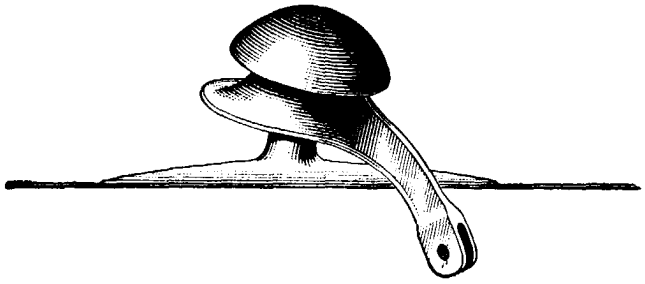

FIG. 11.

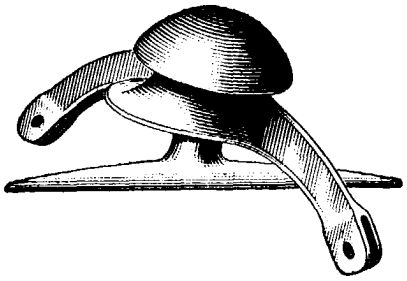

FIG. 12.

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

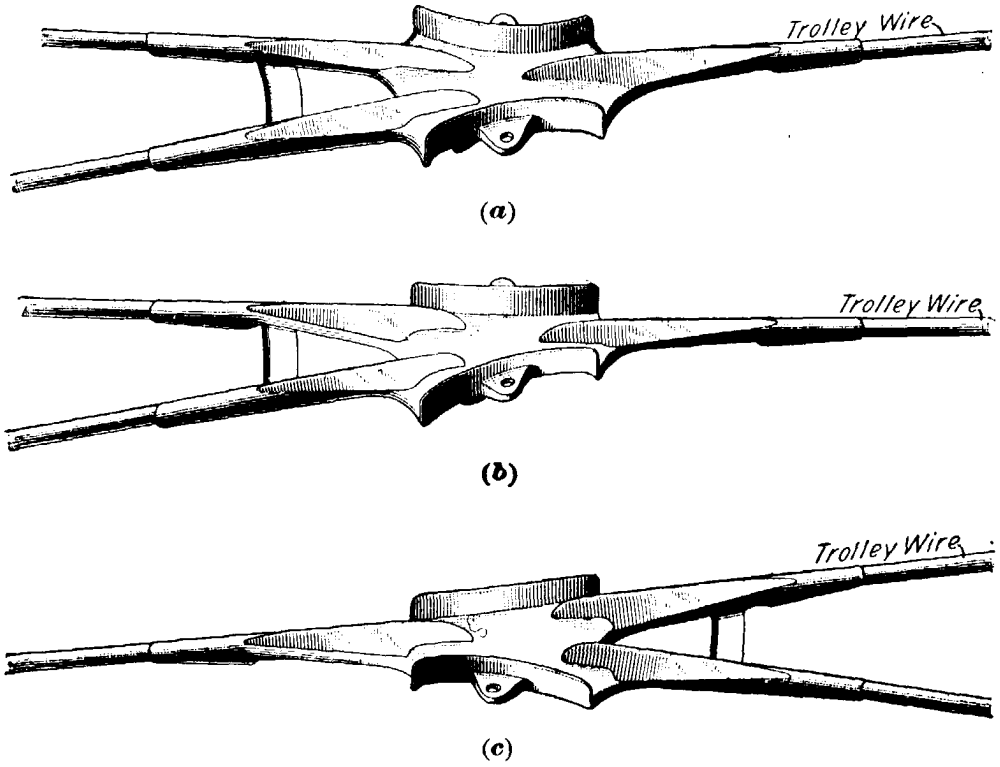

FIG. 13.

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

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

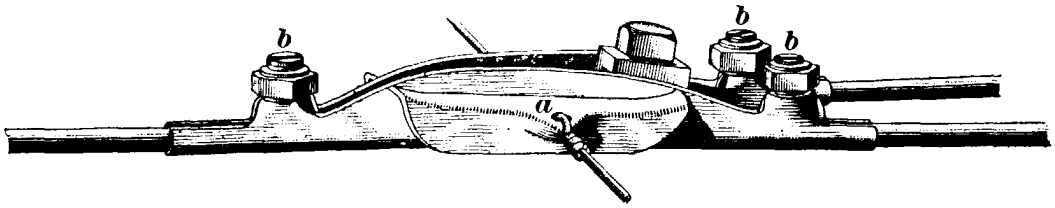

FIG. 14.

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*.

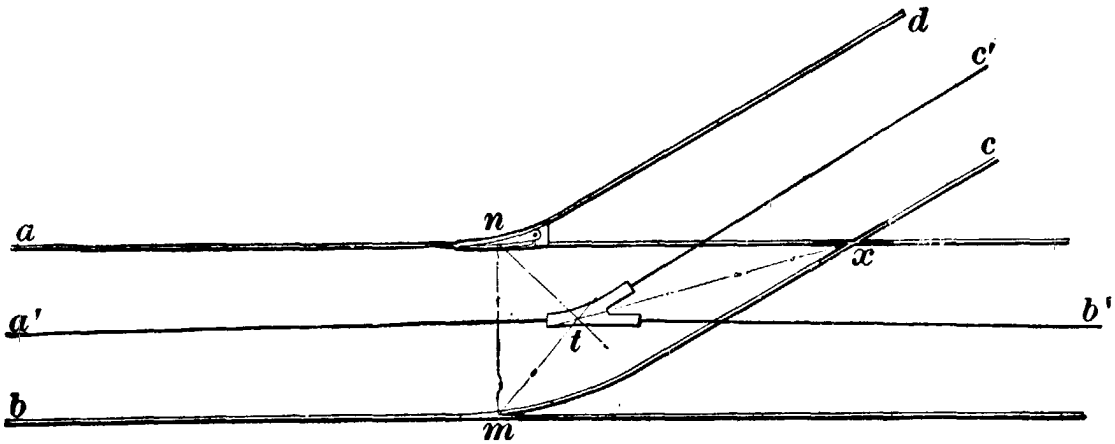

FIG. 15.

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.

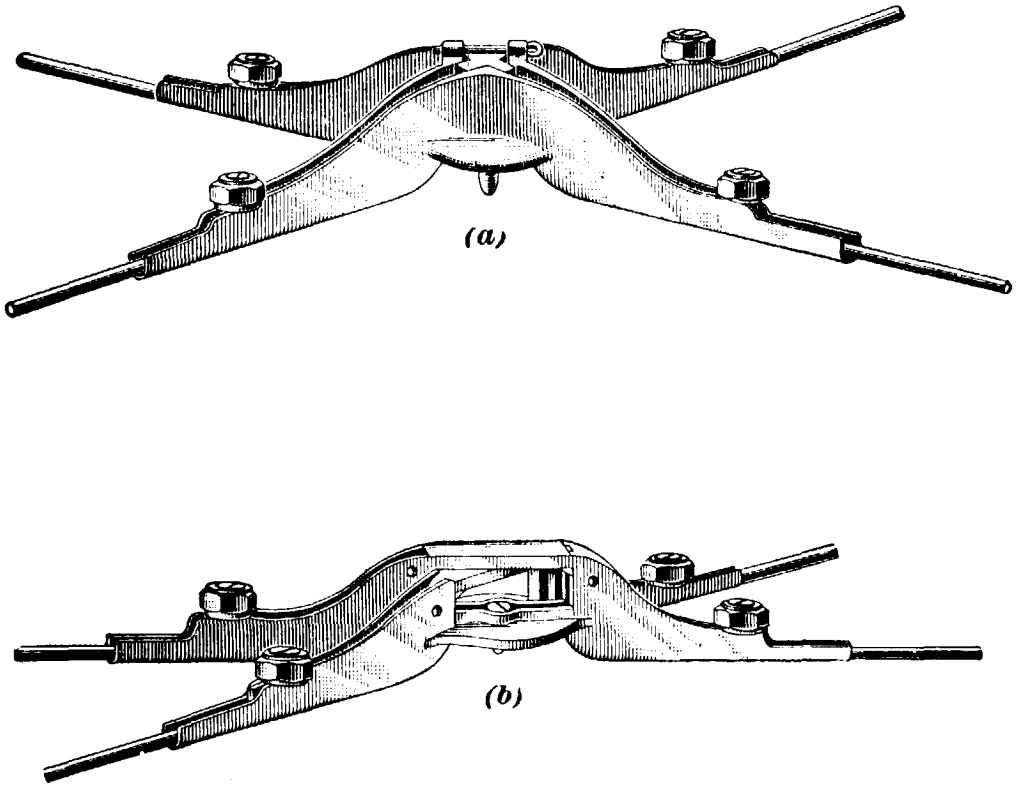

FIG. 16.

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

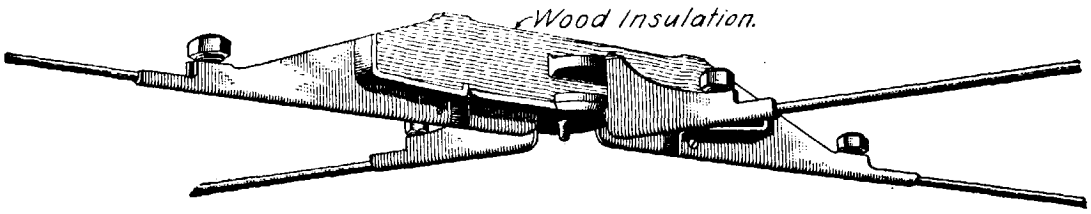

FIG. 17.

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.

12. Section Insulators.—Section insulators are used at the junction of two divisions that are fed by separate feeders

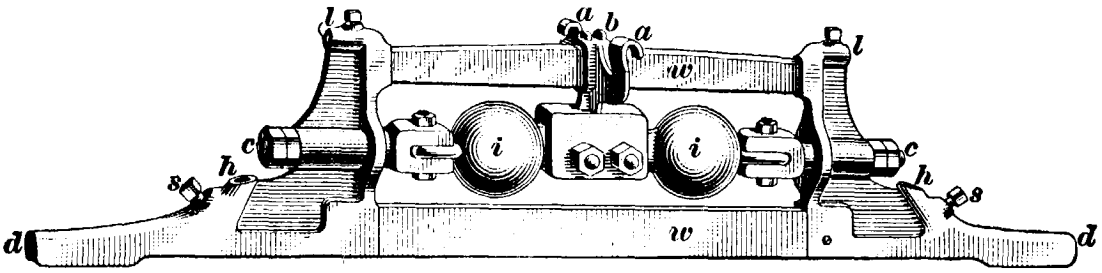

FIG. 18.

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.

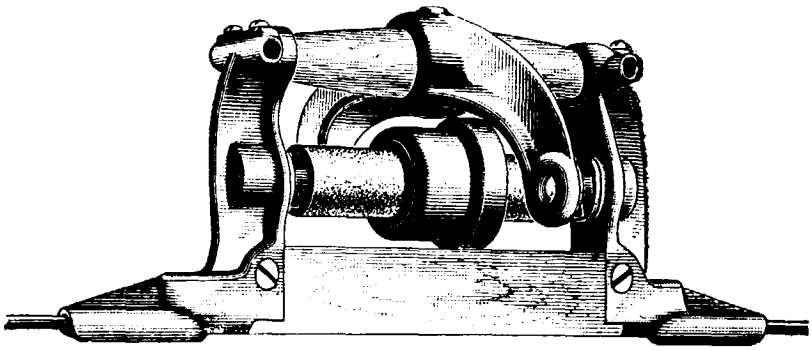

FIG. 19.

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.

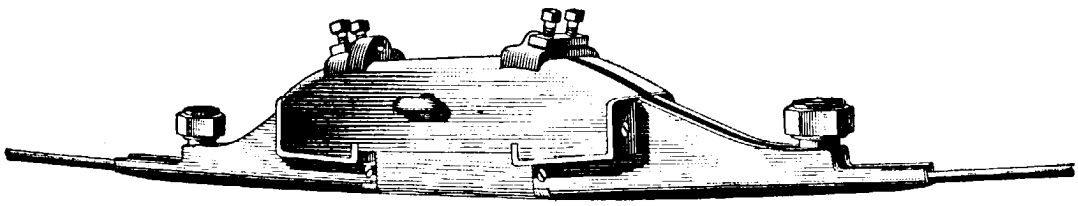

FIG. 20.

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

FIG. 22.

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.

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

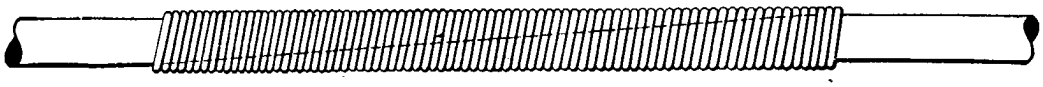

FIG. 23.

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.

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.

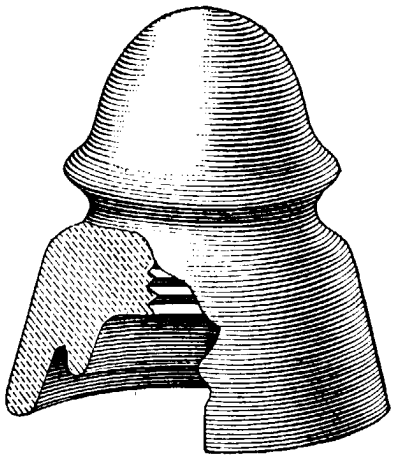

FIG. 24.

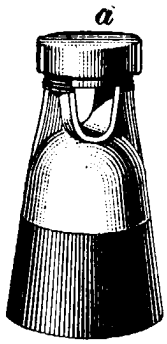

FIG. 25.

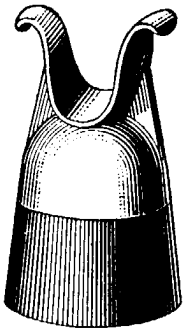

FIG. 26.

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

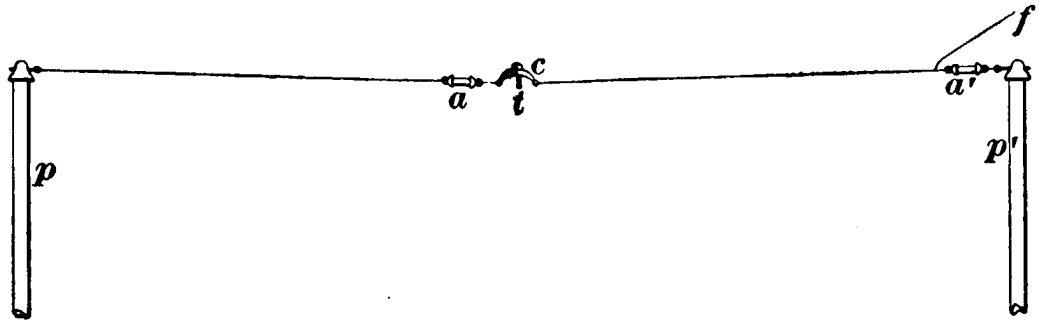

FIG. 27.

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

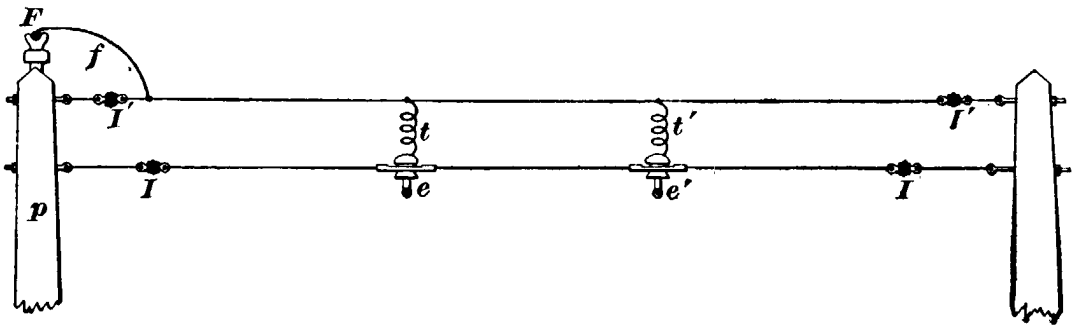

FIG. 28.

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

FIG. 29.

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

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 $10.8 \times 7 = 75.6$ 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

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

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,

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

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,

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

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

* 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

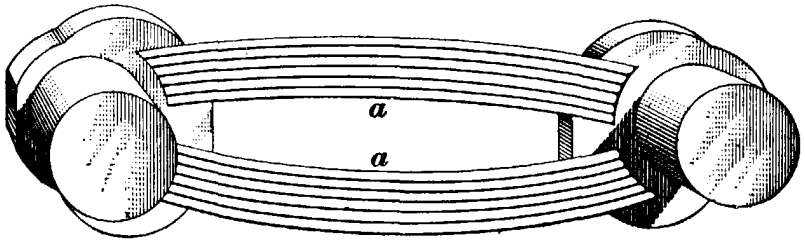

FIG. 30.

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

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

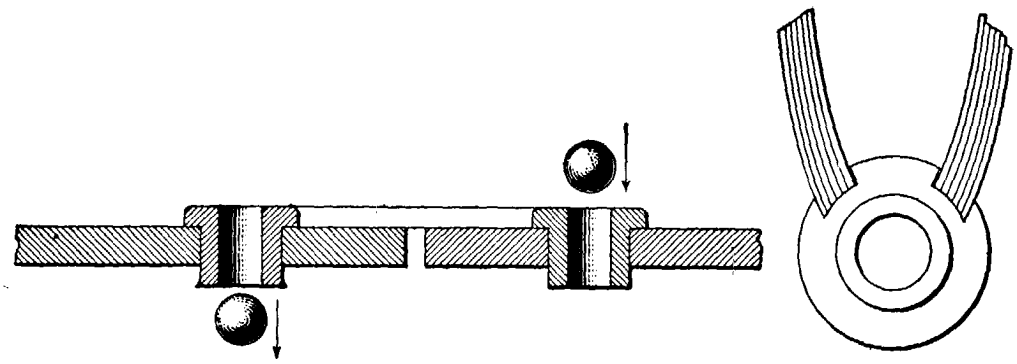

FIG. 31.

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

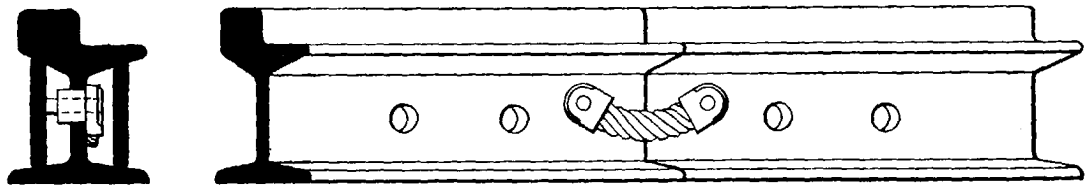

FIG. 32.

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

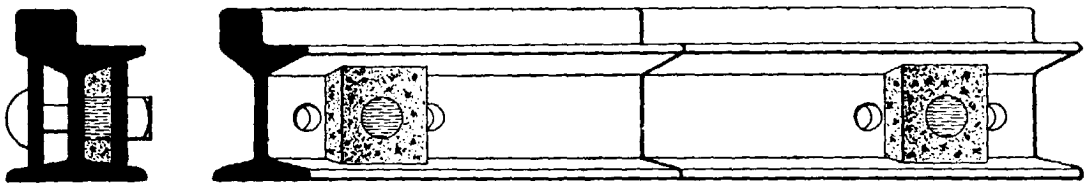

FIG. 33.

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.

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.

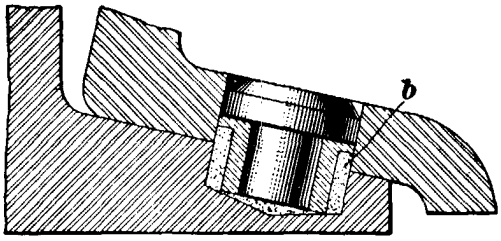

FIG. 34.

34. Disposal of the Bonds.—Having selected the kind of bond to be used in any case, the next question is, how

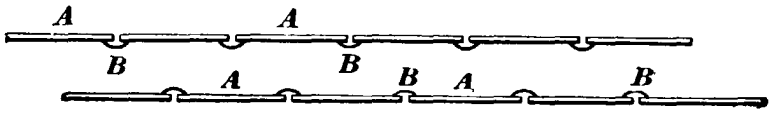

FIG. 35.

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

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.

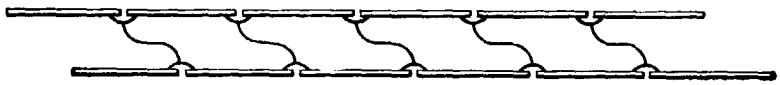

FIG. 36.

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

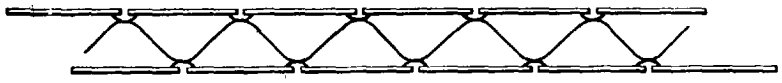

FIG. 37.

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.

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

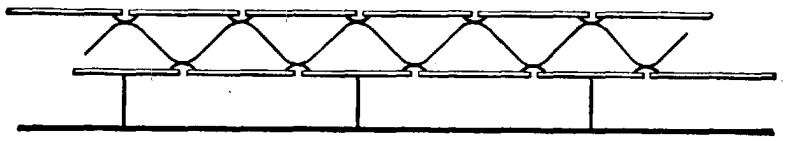

FIG. 38.

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.

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

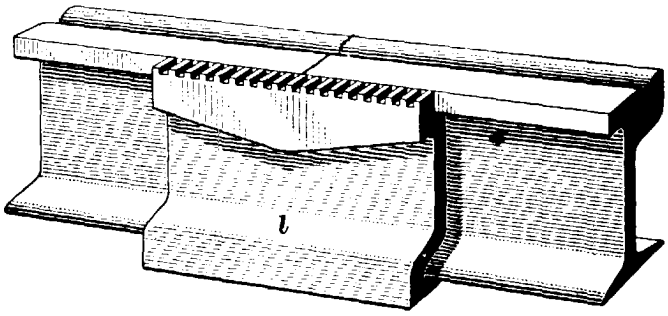

FIG. 39.

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