can be obtained between the outside edge of the rail and the kerb, the division lines of the houses should be shown for the purpose of making a schedule of frontages which the Board of Trade requires.

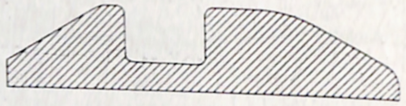


Fig. 59.—Cross-section of an Emergency Rail

Cost of Construction.—The cost of construction of the permanent way varies approximately between £4500 and £6500 per mile of single track, this variation being mainly due to the different classes of paving used. A fair general average of proportionate cost over a system may be taken as follows: Rails and fastenings, including points, crossings, and special work, 30 per cent; paving (sett or wood), including under-bed, 45 per cent (to 50 per cent); labour, including cartage, 20 per cent; bonding, 2 per cent; watching and sundries, 3 per cent.

CHAPTER IV

RAIL BONDING AND WELDING

The Track as Return Conductor.—In the majority of cases, the track rails of an electric tramway are used as the return conductor for the current from the car motors. In early days of electric tramway work it was assumed that the ordinary fish-plated rails would, with the earth itself, form a satisfactory return conductor, and that no further precautions needed to be taken. The electrical resistance at the fish-plated joints, however, was such as to cause the current to flow from the rails on to water, gas, and other pipes in the vicinity of the rails, and from these back into the earth again, causing electrolytic corrosion of the pipes at those points. To prevent this leakage of current from the rails, they were bonded together at the joints, and thus the leakage into the earth at any point is small—though the total amount in a long length of line may be large—and thus causes little damage.

Board of Trade Requirements.—The Board of Trade requires that a continuous record be kept of the difference of potential, during the working of the tramways, between the point of the uninsulated return farthest from and nearest to the power-station. If at any time the difference should exceed 7 volts, steps must be taken to reduce it below this limit. The test is made by means of a recording voltmeter connected between the negative bus-bar in the station and the point of maximum drop. The Board of Trade also requires that any uninsulated return shall be connected to the negative terminal of the generator, and the negative terminal of the generator shall be connected through a current indicator to two earth-plates not less than 20 yards apart. These two earth-plates must be so laid that an E.M.F. of 4 volts shall produce a current of at least 2 amperes between them, and a test of this must be made at least every month. Under the above conditions, the current passing from the earth

connections to the generator shall not exceed 2 amperes per mile of single track, or 5 per cent of the total current output of the station. These two regulations make it imperative that the return circuit should be well bonded.

The first condition means that the drop of potential in the return circuit shall not exceed 7 volts. The drop in volts is, of course, the current passing multiplied by the resistance, and therefore, to keep within the Board of Trade limits, it is necessary to keep the resistance of the return as low as possible. The higher the resistance of the return, the shorter is the length of the section which can be operated without the use of track feeders or negative boosters.

The second condition simply means that the return must be of such a resistance that there will be very slight leakage to earth.

Rail-return Cables and Boosters.—In the case of some long lines, even the bonding of the rails will not bring down the potential at the farthest ends below the 7 volts limit, and then special insulated rail-return cables are connected to the rails at various points, and the other ends of these cables are coupled on to negative boosters in the power station. The potential at these points is thus easily kept within the required limits, and hence also that of the entire system. For further particulars about the use of boosters, see the section on Cables and Distribution System.

Instead of copper-bonded fish-plated joints, the rails are often welded together at the joints. The various forms of welded joints will be considered after rail bonding.

RAIL BONDING

Definition and Historical.—A railbond is a device which makes electrical connection between two lengths of rail just in the same way as a fish-plate makes mechanical connection between them. The name railbond is, of course, an abbreviation of electrical railbond.

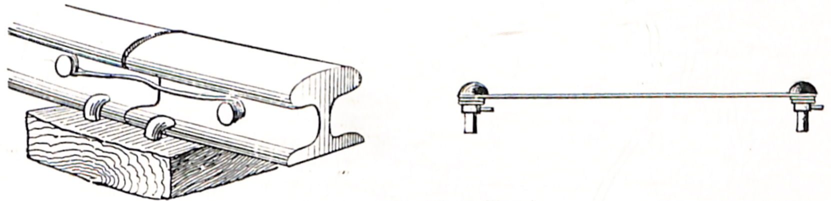


Fig. 60.—Old-style Railbond

The earliest bonds were simply pieces of iron wire, fixed to rivets driven into holes in the web of the rail. The wire was either plain or galvanized, and the ends were twisted round the rivet in much the same way that connection is made to a terminal post on any electrical instrument (fig. 60).

The weak points about this method were that the rivet did not make a good electrical contact with the rail, and as the wire was wrapped round the rivet there was a large surface exposed to oxidation. The next step was to use a copper wire, or a flat piece of copper brazed or riveted on to the rail (fig. 61). The trouble again was that the contact was not good.

The channel-pin method was then used, and this made a fairly good connection. A steel taper plug, as shown in fig. 62, was driven through a hole in the rail with a piece of ordinary trolley wire. The groove in the side of the plug was the same size throughout, and was made of a size to take a standard trolley wire. The plug, being tapered, forced the trolley wire into close contact with the inside of the hole in the rail. Channel-pins are used even at the present day on some Continental lines and in places where the loss in the return is not of great importance. This method failed owing to the very small surface of contact which was obtained.

Conditions to be fulfilled.—The following conditions should be fulfilled by any bond:—

1. The contact area between the bond and the rail should be about eight times as great as the cross-sectional area of the bond itself. This is necessary, because the conductivity of steel is only about one-eighth the conductivity of copper. In most modern types, which are described later, it will be found that the surface of contact between the bond terminal and the web of the rail bears this ratio to the cross-section of the bond.

2. The bond must be durable both as regards material and also as regards resistance. This makes it essential that the connection between rail and bond should be such that the contact will not deteriorate, and that the bond itself shall stand being buried in the ground.

Fig. 61.—"Brooklyn" Railbond

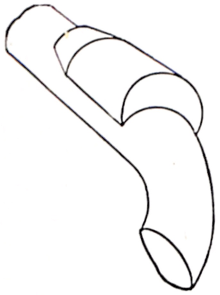


Fig. 62.—Channel-pin

3. The bond must be one which can be easily fixed. It should therefore be composed of as few parts as possible, and must be such that it can be applied without elaborate appliances or expensive supervision.

4. The bond must be cheap in prime cost.

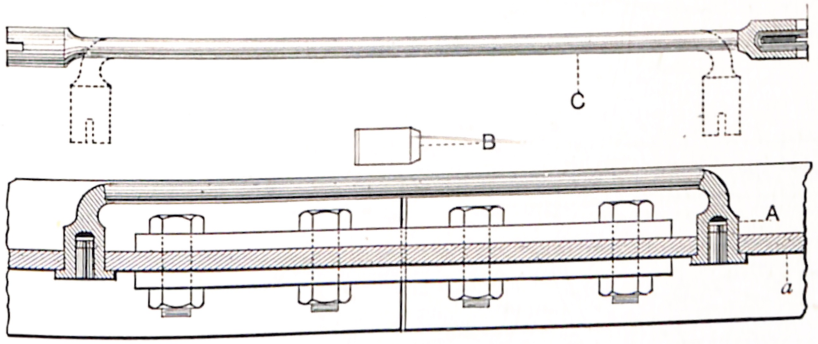
The two first may be called the engineering conditions, and the last two the commercial conditions.

It would doubtless be possible to design bonds which would satisfy the two first conditions, but they might require the use of elaborate appliance or of great care in fixing. It should never be forgotten that railbonds form a part of a commercial undertaking which has for its object the payment of interest on capital expenditure. The following descriptions cover all bonds which are commonly used in this country, and also one or two which have been tried, but not to a sufficient extent to determine their comparative value.

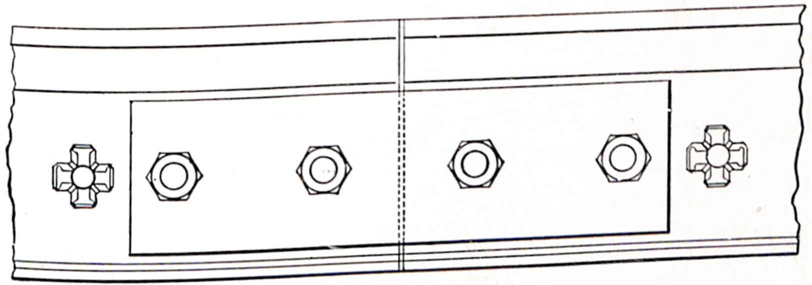
The Chicago Railbond.—This is probably the best-known copper bond which has ever been used, and was the first bond which really combined the necessary conditions already explained.

The railbond C (fig. 63) is a copper rod or wire having thimble-shaped terminals which are bent at right angles to the connecting rod. The whole bond is composed of one solid piece of rolled copper.

In applying the bond, holes are drilled in the web of the rail, into which the thimble-shaped terminals are inserted. The slitted ends of the terminals are spread or clinched over on the rail with a punch; this prevents the bond terminal from drawing back out of the hole. The drift-pin B, which is about one-sixteenth larger than the opening in the terminal, is then driven into the terminal with a hammer. As the drift-pin is forced into the terminal it forces the copper into close contact with the web of the rail, so that there is no chance of corrosion or electrolysis. Owing to the cylindrical shape of the terminal it is possible to obtain a large area of contact between the terminal and the rail. The whole of the bond should be painted with a preservative paint immediately after application, as this increases the life of the bond very considerably.



SECTIONAL VIEW.



ELEVATION VIEW.

Fig. 63.—Chicago Railbond

The Chicago bond is made of any length and in four different gauges, viz. 1/0, 2/0, 3/0, and 4/0 B. & S. gauges; the dimensions of the four sizes being as follows:—

Size of Wire, B. & S. Gauge.	Diameter of Connecting Wire.	Diameter of Hole in Rail into which Terminal of Bond fits.	Diameter of Hole in Terminal.	Depth of Hole in Terminal not including Point.	Diameter of Pin.
	Inches.	Inches.	Inches.	Inches.	Inches.
4/0	0.46	7/8	7/16	1	1/2
3/0	0.409	3/4	3/8	1	7/16
2/0	0.364	5/8	5/16	1	3/8
1/0	0.325	1/2	1/4	1	5/16

It should be noted that with a Chicago bond the area of contact between the terminal and the web of the rail is about eight times the cross-sectional area of the connecting wire. This, as already explained, is a most important point.

Crown Railbonds.—The one disadvantage of the Chicago bond is that it is necessary to have access to both sides of the rail in order to apply the bond. This is, of course, a point of considerable importance when an existing tramway is being reconstructed or when bonds have to be replaced.


Fig. 64

The "Crown" solid bond was designed to embody all the advantages of the Chicago, with the additional advantage that it could be applied from one side of the rail. It will be seen that the only difference between the Chicago and the Crown bond lies in the terminal. No special tool is needed to hold the bond in place, and so simple is the construction of the bond that any ordinary workman can apply it. In the latest form, to obtain greater flexibility, a strand made up of small wires has been substituted for the solid connecting rod. The terminals are *welded* on to the connecting strand, and a cross-section through the junction of the terminal and the strand shows a homogeneous structure in which the separate wires of the strand cannot be distinguished.

The following illustrations show in detail some of the mechanical features common to Crown bonds:—

Fig. 64 shows the steel expanding pin used with *all* Crown bonds. This pin is one-sixteenth inch larger than the hole in the terminal, so that, as it is driven into the terminal, it will press the copper outwards in all directions radially from the centre line of the pin. The following are the diameters of pins regularly used with all styles of Crown railbonds:—

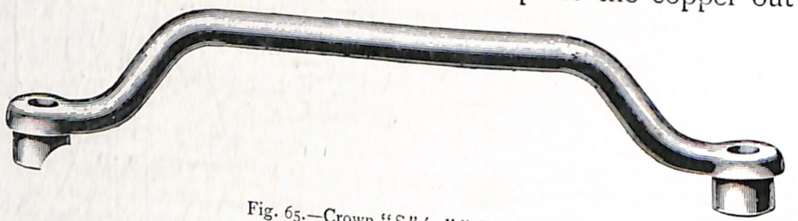


Fig. 65.—Crown "S" (solid) Bond

Size of Bonds.	Diameter of Pins.
4/0	$\frac{1}{2}$ inch.
3/0	$\frac{7}{16}$,,
2/0	$\frac{11}{32}$,,
1/0	$\frac{1}{4}$,,

Fig. 65 gives a full view of a Crown "S" (solid) bond, drilled and milled ready for insertion in the web of the rail. Fig. 66 shows, in cross-section, the terminal fixed in the web of the rail.

A full view of a flexible bond is given in fig. 67, which shows the style of terminal used on all flexible Crown bonds. Fig. 68 shows in cross-section the same terminal fastened within the web of the rail. Notice in figs. 66 and 68 that the pin, as it is hammered home, has expanded the copper on the farther side of the web to form a burr. No special tool is required to produce this burr, which effectively fastens the terminal, serving the purpose of a shoulder or riveted head.

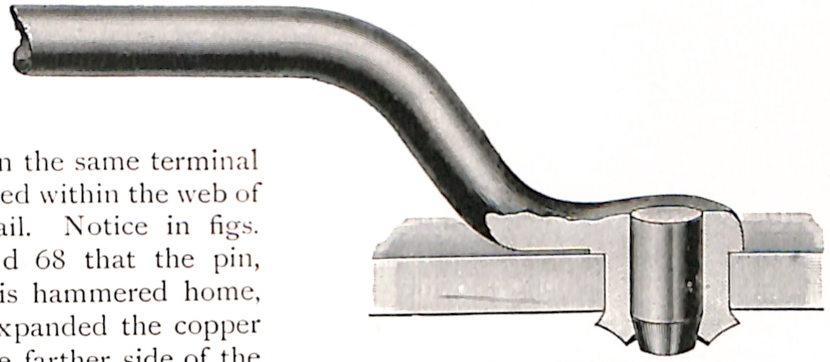


Fig. 66.—Solid Crown "S" Bond Terminal fixed in Rail


Fig. 67.—Crown Flexible Bond

It is evident that the terminal of the Crown bond takes up less room than, or rather does not project so far from the web of the rail as, the old Chicago type. It is therefore possible to use this type of bond between the fish-plate and the web of the rail simply by flattening the connecting strands.

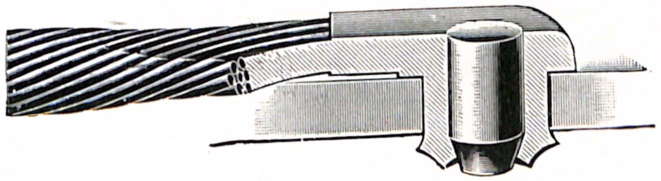


Fig. 68.—Crown Flexible Bond Terminal fixed in Rail

The advantages of placing a bond under the fish-plate are, that it is protected from mechanical injury and, to a certain extent, from oxidation. As the bond is of necessity shorter than a bond which spans the fish-plate, it introduces a smaller resistance into the return circuit. The special bond for use under fish-plates is made with a flexible strand, either straight or crescent-shaped between the terminals, as shown in figs. 69 and 70. In both cases every wire in the strand is made with a curve, which gives


Fig. 69

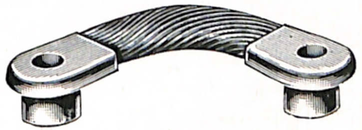


Fig. 70

Special Crown Bonds for use under Fish-plates flexibility and permits elongation of the strand itself without tension on the individual wires. In the crescent-shaped Crown "T" bonds the curve of the strand readily permits the terminals to spring farther apart or closer together when the rails contract or expand. In the straight bond, to provide additional length of each wire to compensate for the contraction of the rails, the strand is pressed back so that it bulges sidewise midway between the terminals. This makes the wires long enough for the terminals to be drawn apart ½ inch without putting the individual wires in tension.

When the rails expand, the already curved wires will close together more tightly, and the terminals may come ½ inch nearer together without distorting the bond. As rails are never allowed much more than ¼ inch space between them, this bond provides amply for the most severe cases of expansion and contraction. In order to use these bonds under the fish-plate it is necessary to have at least a clearance of 5/16 inch between the fish-plate and the web of the rail.

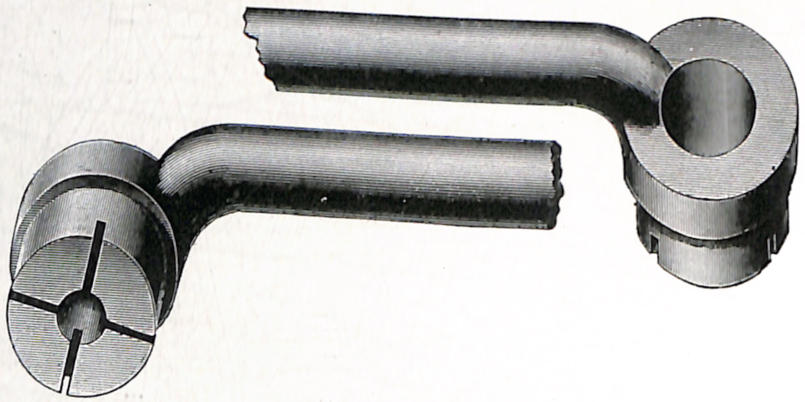


Fig. 71.—Neptune Bond

Neptune Bond (fig. 71).—This bond is of German manufacture, and is almost identical with the Crown bond. The Neptune terminal, however, differs from the Crown terminal in the following way: The hole in the terminal of the Crown bond tapers only slightly throughout its length, whereas in the Neptune bond this hole is much smaller at the lower end, and this end is slit. It is claimed that this construction gives a better contact between terminal and rail. It seems more probable that the drift-pin, meeting an obstruction at the point where diameter is reduced, would simply drive the metal out of the hole in the rail instead of forcing it radially against the sides.

The Neptune bond is made in the following gauges, and of any length desired:—

Gauge of bond	1/0	2/0	3/0	4/0
Sectional area, square inch ...	0.082	0.0951	0.1256	0.169
Diameter of hole in rail	½	⅝	¾	⅞
Diameter of hole in bond-head ...	5/16	5/16	7/16	½
Diameter of pin	⅜	⅜	½	9/16

Columbia Bond (fig. 72).—This bond consists of a copper rod with solid truncated cone ends and two specially shaped copper thimbles. The inside of the thimble is tapered to fit the bond-head, and the outside is tapered in the opposite direction.

The cone-heads are placed in the holes in the rail, and the thimbles are slipped over them from the opposite side. The two parts are gripped in a portable screw or hydraulic press, and the bond-head is forced into the thimble. In this bond there are two contacts—one between rail and thimble, and the other between thimble and main body of bond. It is claimed, however, that such intimate contact is obtained that it is impossible for these surfaces to oxidize or for the thimble to shake loose.

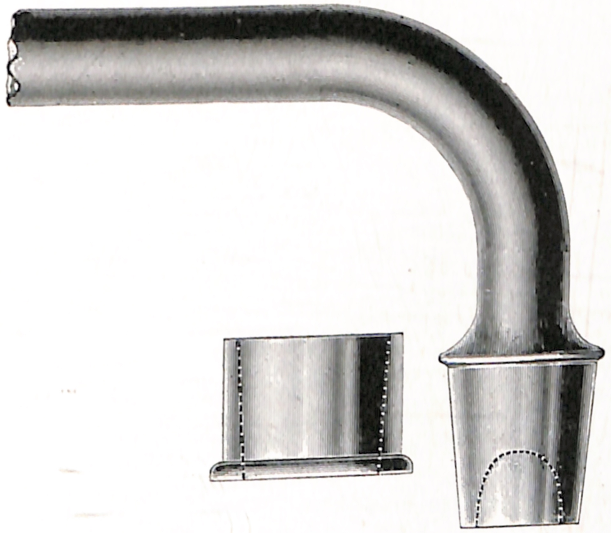


Fig. 72.—Columbia Bond, End and Thimble, full size

Plastic Bonds.—All bonds described so far have been similar in principle, but have differed in mechanical details. Mr. Harold P. Brown, who was for many years with Edison, introduced the plastic bond, which differed absolutely from anything that had been previously attempted.

The first form of plastic bond consisted of two cork cases and two plugs of plastic amalgam. The cork cases are placed under the fish-plate as near the ends of the rail as possible, and are then filled with the plastic amalgam. The fish-plate is then fixed in place, and a circuit is established from the rail through the plastic plug to the fish-plate, and then along the fish-plate and back through the other plastic plug to the rail.

In order to make good contact between the plastic plug and the rail and the fish-plate, a contact spot was cleaned on the two latter, and this spot was amalgamated by means of a special alloy in the form of a stick. The plastic plugs really form the bond. The cork cases are only intended to protect the plastic metal from oxidation, and to keep it in position, opposite the specially prepared spots on the rail and fish-plates. The contact area between the rail and the plastic plug is calculated to be ⅙ inch for each 10 lbs. weight of rail per yard. Thus a 90-lb. rail requires a contact surface of 1.5 inch. The cork cases are made so that the thickness equals twice the clearance between the fish-plate and the web of the rail. For a clearance of ¼ inch a cork case ½ inch thick should be used.

The plastic compound is packed in small wooden boxes, each of which holds the exact amount necessary to make one contact between rail and fish-plate.

The solid alloy for amalgamating the contact spots on rails and fish-plates is in hermetically-sealed cylinders containing about 1 lb. The rod of alloy should be sealed up when not in use, as the metal softens on exposure to air. When track is being laid, the plastic bonds should be applied by the platelayers. One extra labourer to clean the contact spots, and one to amalgamate them and put the bonds in place, should be added to the gang. The spots on the rail and fish-plate can be cleaned either with a flat-nosed drill or by means of a special emery grinder which is illustrated in fig. 73.

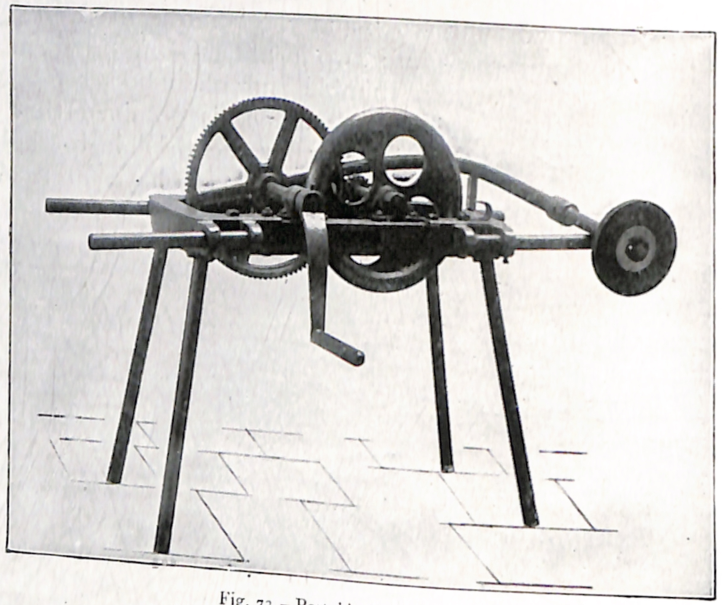


Fig. 73.—Portable Emery Grinder

A later type of bond is that known as the "Copper" plastic. This bond was devised in order to obviate the necessity of using the fish-plate as part of the bond. The plastic copper bond consists essentially of a rectangular piece of rolled copper made to fit between the fish-plate and the web of the rail. The length is such that it will just fit in between the end bolts of the fish-plate (see figs. 74 and 75). A cup-shaped projection is pressed at each end of this piece of copper in order to ensure a good contact between it and the web of the rail. The entire surface of the

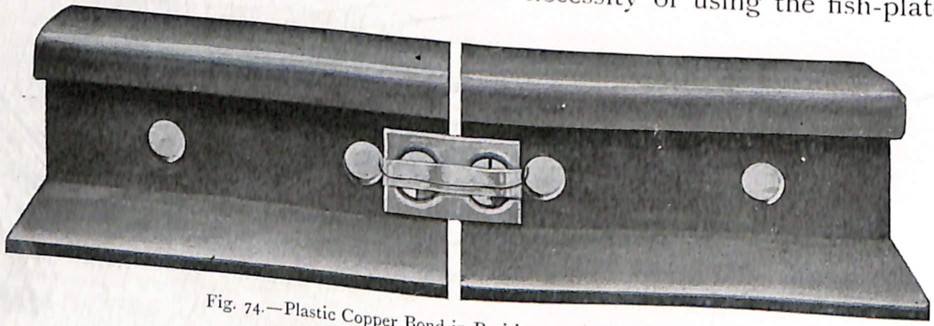


Fig. 74.—Plastic Copper Bond in Position, ready for Fish-plate

copper strip or bond, as it may be called, is amalgamated with a plastic alloy similar to that used with the old-type plastic bond, and spots are cleaned on the web of the rail to correspond with the two projections on the copper. In order to keep the bond in contact with the web of the rail, strong spring washers are placed inside the cupped projections, and these are of such a size that they exert a pressure of about 2000 lbs. on the copper when the fish-plate is screwed up tight. In order to prevent the washers from cutting through the copper, a sheet of thin steel is interposed.

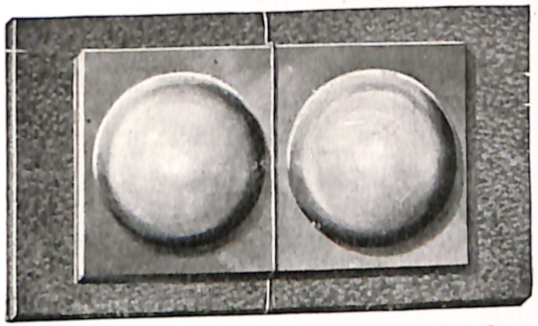


Fig. 75.—Front View of Plastic Copper Bond with Cork Case

WELDED JOINTS

General Considerations.—Welded joints would not do in railway work, as the rails would then become twisted and bent out of their place, due to the expansion and contraction caused by variations in temperature. Tramway rails, however, being held in position by the set stones or other material in which they are embedded, as well as by numerous tie-bars, cannot be so bent out of their place.

The only effect of variations in temperature is to set up a tensile or compressive stress in the rails. The amount of stress set up for a given variation in temperature can be easily calculated from the coefficient of expansion and the modulus of elasticity of the steel of which the rail is made. The result of such a calculation shows that a variation of 10° F. in the temperature will set up a stress of 1 ton per square inch in the rails. As the elastic strength of steel rails is seldom less than 19 tons per square inch, and the ultimate strength about 35 tons per square inch, it is easily seen that for any variations in temperature that might occur in a climate such as Britain, no dangerous stresses can thereby be set up in the rails.

The principal advantages which welded joints have over ordinary fish-plated ones are: first, that the rolling-stock runs much more smoothly over them—indeed, so far as the welded joints are concerned, the rails are practically continuous; secondly, that the electrical conductivity of the joint is as good as, and sometimes better than, that of the rail itself; and lastly, that the joint, if properly welded, is likely to remain so, and not deteriorate, as many fish-plated and ordinary bonded joints do.

One disadvantage of welding is that by the application of too great a heat the rail is apt to be burnt, and its temper to a great extent destroyed; and if this happens it is sometimes so weakened that the stress set up in the rail, due to cooling at the joint after welding, is sufficient to cause fracture after the rail has been in use for a very short time. Another disadvantage is, should at any time a length of rail require renewal, due to ordinary wear and tear, it is necessary to saw it through at both ends before it can be taken out, and this entails considerable time and labour. It would seem to be best practice to weld only every three or four consecutive joints, and then copper-bond the fourth or fifth. There are a number of ways in which the actual welding of the rails has up till now been carried out.

The Falk Cast Weld.—One of the earliest methods is that employed in the Falk cast weld. The ends of the rails to be so welded are brought close together, or if the rails are already laid, and do not butt close up against one another, a thin piece of steel of the same section as the rail is slipped in between the rails so as to make a tight joint. The ends of the rails are then treated to a strong sand blast, which cleans away any scale, &c., on the rails, so as to allow the cast iron which forms the joint to come in direct contact with the body of the rail. The sand used in this blast is very fine, and is specially dried before it is used.

The power for the sand blast is usually obtained from a motor-driven compressor or blower on a special car. The sand, which is stored in a box or bunker, also in the car, is led into the air-pipe which comes from the blower, and is carried along with the air into the flexible pipe and nozzle, from which it is blown with a great velocity against the rails. The sand-blast car is usually equipped with a traction motor, and receives its power, both for locomotive purposes and for driving the blower, from the overhead trolley wires, which are erected before the rails are welded.

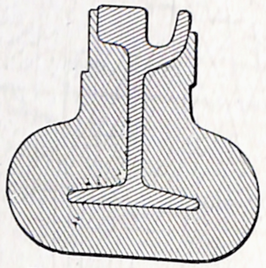


Fig. 76*a*.—Section of Falk Weld Joint

Coming now to the actual welding, a special iron mould is fixed firmly in position round the rails at the joint, and cast iron, which has been melted in a special crucible or cupola (fig. 76), is poured into the mould. The cast iron is heated to a considerably higher temperature than that necessary to melt it, and is poured into the mould at the side next the web, which is therefore heated most. The cast iron, on coming into contact with the sides of the mould, cools there first and partly solidifies, and the great pressure which is set up, due to the expansion of the cast iron on cooling, does not act so much between the cast iron and the mould as between the cast iron and the web and flange of the rail, where the heat is most intense.

This great pressure causes the cast iron, while yet liquid, to be forced into and to penetrate the interstices in the metal of the web and flange of the rail. In this way a very satisfactory and highly conductive joint is obtained. After the cast iron is set, the mould is easily unclamped and knocked away; a section of the joint would then appear as in fig. 76*a*. This form of joint, though not a true weld, is practically as good as one; but the inconvenience of carrying about a portable cupola is very great, besides being somewhat costly, and has to a great extent prevented the wide adoption of this method.

Thermit Welding.—A more recent method of rail-welding is by means of thermit. This process was first introduced by Dr. Goldschmidt in Germany, and is now carried out by a company under his patents. To

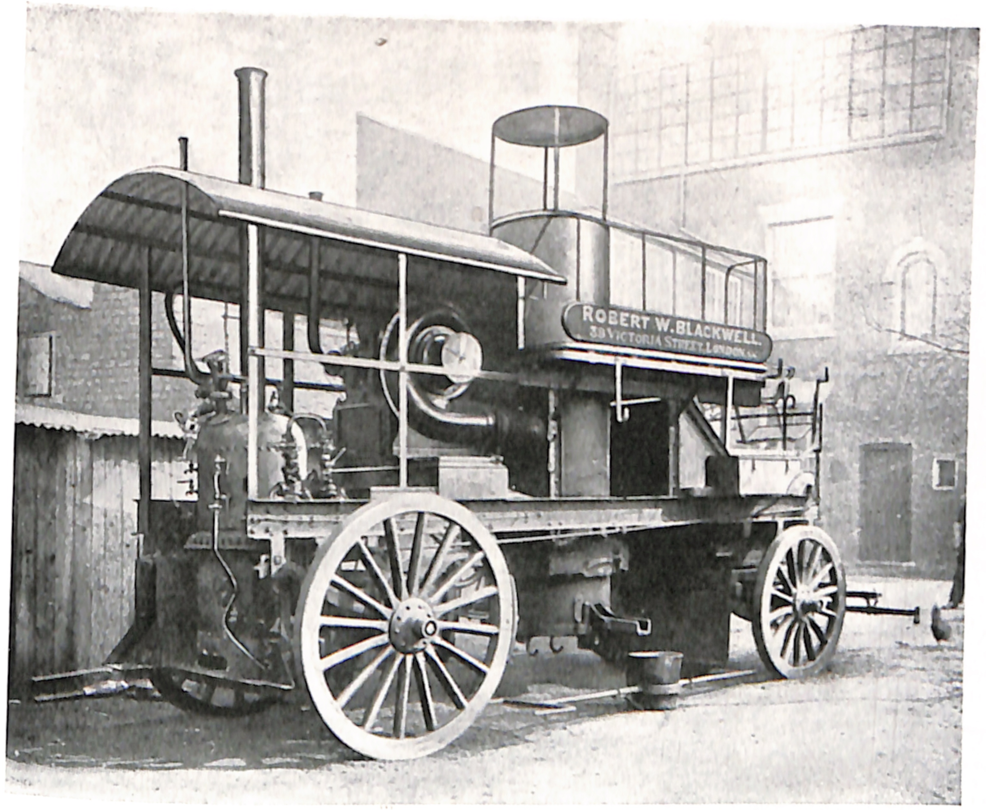


Fig. 76.—Cupola on Wheels, used in making the Falk Weld Joint

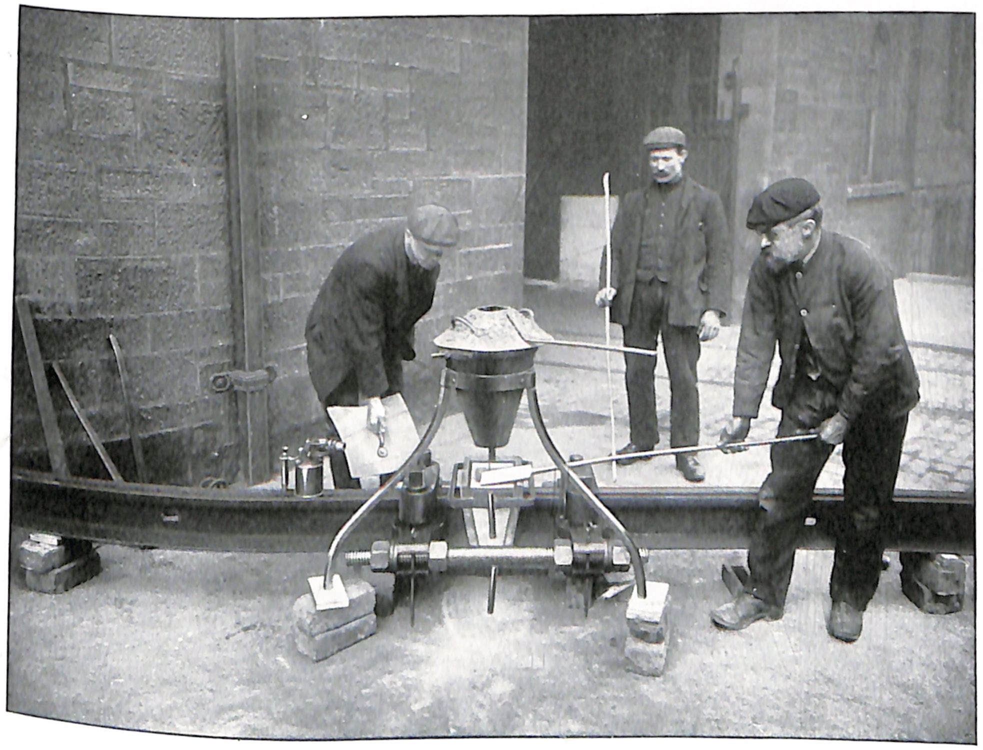


Fig. 77.—Thermit Process of Rail-welding

a certain extent it is a return to the Falk cast weld, but the inconvenience of requiring a portable cupola is done away with. The weld is carried out as follows:—

The ends of the rail to be welded are clamped in position, and special moulds are fitted round the joint. These moulds are formed of rock sand, compressed into shape and baked hard. The small interstices between the mould and the rail, that is, where the mould fits against the rail, are closed by being painted over with fine clay, which is also used to cover the surface of the rail. After the mould is fixed in place, both it and the parts of the rail at the joint are thoroughly dried by means of portable blow-lamps, as it is necessary that all moisture be driven from the mould before the thermit is run in.

Thermit is a powder consisting essentially of aluminium in a finely divided state and of iron oxide. This powder is filled into a conical-shaped crucible placed immediately above the joint, as shown in fig. 77. The bottom of the crucible has a small opening which is stopped up by means of a small iron rod. This rod projects down out of the crucible, and when the thermit is melted it is knocked up inside the crucible by a spade-like implement, and the molten metal runs into the mould. The chemical action is started by means of a special firing powder, and immediately thereafter a loose-fitting lid is placed over the crucible to prevent part of the contents being blown out all around, the action being very violent. The action is due to the property which aluminium has of having a very great affinity for oxygen at high temperatures; this it seizes from the iron with great evolution of heat, which causes the whole mixture to pass into a molten state.

The fusion temperature developed is about 3000° C., and when the crucible is pierced the heavy iron flows first into the mould, and heating the foot and web of the rail melts them together with itself into a homogeneous mass. The lighter aluminium oxide flows after and fills the mould right up over the head of the rail and heats it, causing a partial weld, and in this way a better and truer weld is caused than that due to the cast iron in the "Falk" process. Dr. Goldschmidt introduced a special method of mixing and firing so as to make the action more gradual, otherwise the lid of the crucible would almost certainly be blown off and the contents spilt. After the joints are cool, the moulds are broken off and the surface of the rail ground down so as to do away with any slight inequality in the surface of the rail at the joint. This is done by an emery wheel, which is driven by means of a belt from a motor, the whole being mounted on a special car.

The danger of overheating occurs to a certain extent with thermit welding, and care is therefore required that the ingredients of the powder are mixed in the right proportions. The presence of any moisture in the mould, or too thick a layer of clay on the top of the rails, seems to cause the thermit to take longer in setting, with consequent overheating and burning at the joint. Fracture then ultimately takes place at these joints.

Electric Welding — Lorain Steel Company's Process. — Electric welding was introduced by the Johnson Company of Boston, U.S.A., and was later carried on by the Lorain Steel Company, Ohio, U.S.A.

This method consisted in welding, by means of an electric current, two plates to the rails at the joint, one plate on each side of the web. These plates had three bosses or projections on one side of them, one at the centre and one at each end. These were about $\frac{1}{8}$ inch deep and about 3 or 4 square inches in area (see fig. 78). The plates were placed with the plane sides against the web of the rails, the bosses being used for concentrating the current on the part to be welded. They were, during the process of welding, crushed almost flush with the plate by the hydraulic pressure which was then brought to play on them. Three welds were required to make a joint, one at each end of the plates and one at the centre, i.e. exactly at the joint.

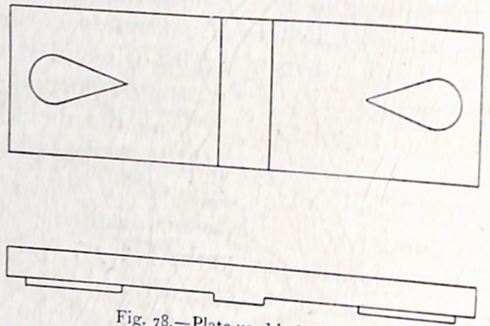


Fig. 78.—Plate used in Welding

The welding plant consisted of five cars: (1) the sand-blast car; (2) welding car; (3) rotary-converter car; (4) booster and motor-car; (5) motor and emery-wheel car for finishing. The cars were run on the tramway lines by their own equipment of motor and trolley.

The secondary of the welding transformer consisted of one turn of copper, the terminals of which formed the clamps that grip the weld. The current used was taken from the trolley line, the connections being arranged as shown in fig. 79. Great pressure, up to 35 tons, was maintained on the joint until it cooled, by an hydraulic jack. This pressure, which prevented crystallization of the steel, and the absence of burning secured by the larger contact area than was at first used in this method, were the improvements which determined the success of this method. The welding transformer was run at 300 volts, from 5 to 7 volts being

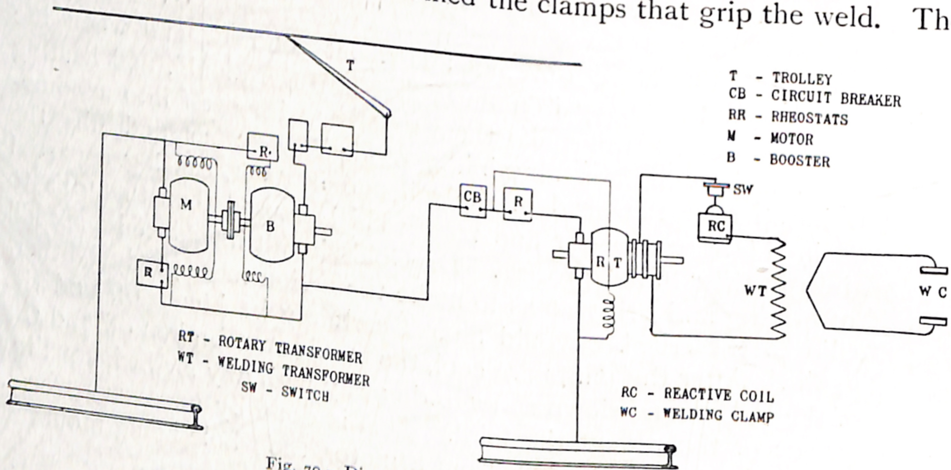


Fig. 79.—Diagram of Connections of Rail Welder

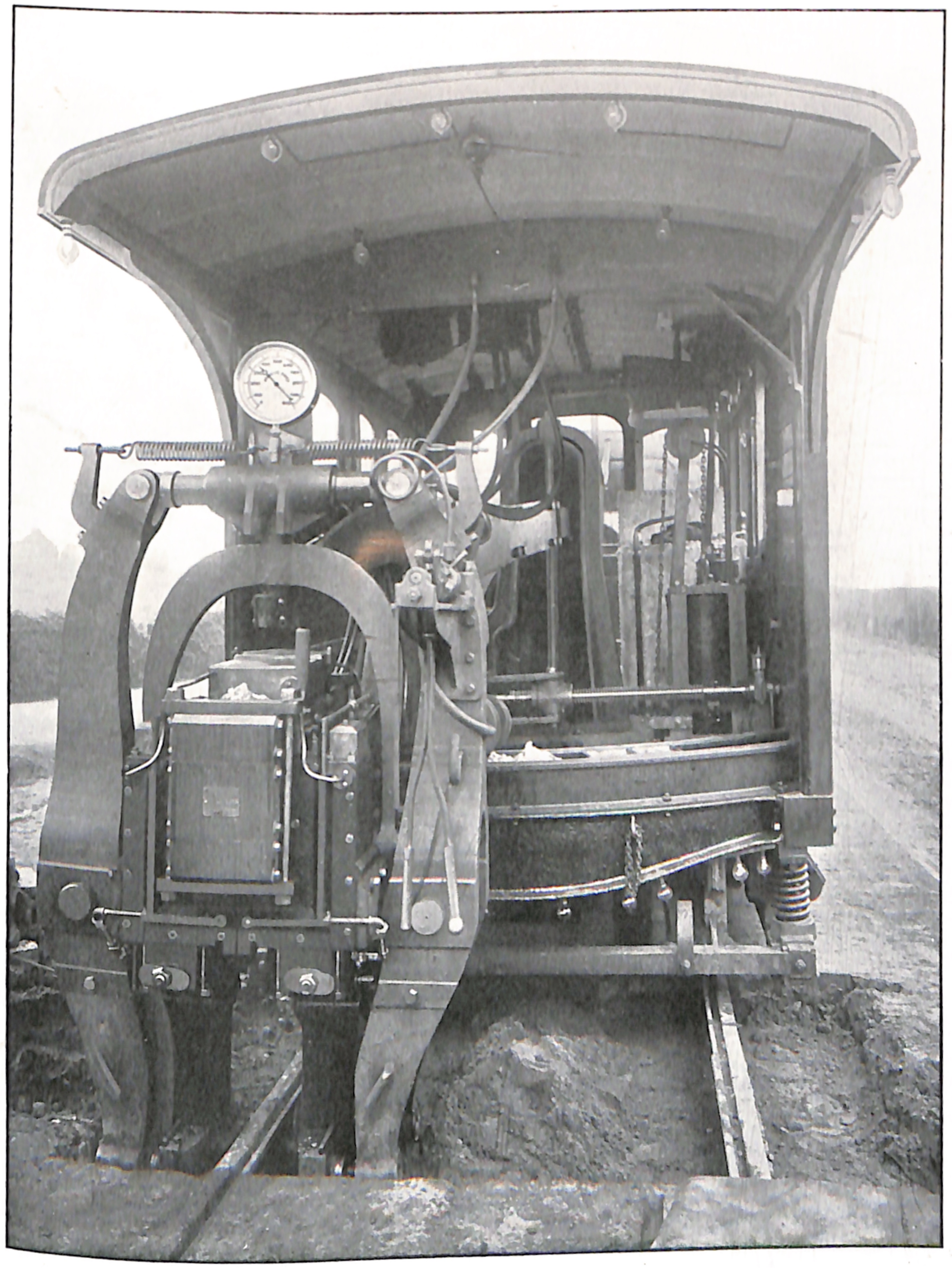


Fig. 80.—Welding Car with Hydraulic Press

maintained at the welding clamp terminals. The welding current ran as high as 25,000 amperes. Fig. 80 shows the end view of the welding car with hydraulic press, in position ready for making a weld.

Arc Light Weld.—This method has been introduced by the Accumulator Manufacturing Company, Ltd., of Berlin. The earlier methods of welding rails direct, by means of continuous current, were not very successful; as the great heat developed caused the structure of the steel of which the rail was composed to change and deteriorate, so that very soon the part at the joint became damaged. Nowadays, therefore, the fish-plates are welded to the flange and head of the rail at the middle (at the gap or joint) and at the ends, on the top of the flange of the rail, and just underneath the head. The flange of the rail is strengthened at the joint by means of a foot-plate which becomes welded to the flange, as shown in fig. 81. Arc light welding is also used to repair worn joints by means of new pieces. The current is taken from the overhead line and converted by a Rosenberg dynamo to a 50-volts supply, 400 amperes being required at this voltage to make the weld. The rail is connected to the positive pole and the negative pole to a carbon (more recently a special form of Swedish steel) pencil. Between the two there exists an arc of about $\frac{1}{8}$ inch long.

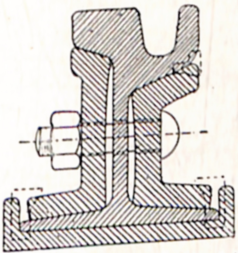


Fig. 81.—Arc-light Welded Joint

Electric and thermit joints, if properly made, have often a conductivity greater than that of the rail itself, and all joints properly welded by any process add considerably to the smooth running of the cars. The most satisfactory results are, perhaps, those obtained by the arc light method.

CHAPTER V

CABLES AND DISTRIBUTION SYSTEM

General Considerations.—The question of the most suitable feeding arrangements for a traction system is one to be answered according to the circumstances governing the particular case under consideration. Obviously, for example, it would be just as bad practice to design the supply of a corduroy track in some primitive neighbourhood for as close voltage-regulation and limitations of rail-potential rise as would be used for a line in a modern city, as to attempt to secure an efficient and trouble-free result by installing amid all the complications of armoured-concrete foundations and urban water, gas, electricity, telephone, telegraph, &c., services, a layout which would be entirely appropriate in a sparsely-populated or uncivilized district. Every case, in a word, must be considered on its merits; when once, however, the rationale of the principles underlying correct design is grasped, a satisfactory solution of the problem for any local conditions can be arrived at.

The limitations imposed upon British practice by the Board of Trade are not unnaturally chafed at by many engineers; but although the attitude of the Board is somewhat unsympathetic to electric traction, and though the utility of certain of its requirements is open to question, there can be no doubt that, broadly speaking, compliance with its regulations does result in the avoidance of vexatious troubles with other authorities. The fact that in America, where there is no statutory limitation of rail-drop, large electric traction companies are at great expense installing negative boosters and rail-return cables for their own protection against ruinous claims for the destruction of metallic property by electrolytic corrosion, is proof-positive of the wisdom of the stringent rules as to the maximum potential-differences of any points of the rails insisted on by the British Government. Granted that the provision and upkeep of boosters and negative cables, with the inherent tendencies to break down through damp inseparable from the latter, are a serious outlay, the collapse of the foundations of a large business block through the weakening of the steel from electrolytic rusting and the bursting of its concrete envelope from the enormous expansive force of the formation of the oxide, would issue in claims for damages which, even if unsuccessful, would involve such losses in legal expenses as would make the saving effected by dispensing with appliances to minimize the mischievous activities of vagabond currents the very falsest of false economies. It is considered best, accordingly, to detail how an urban network complying with British practice would be laid out; exigencies of space preclude the consideration of more than one type, and should the reader find himself untrammelled by regulations in his decisions he can readily omit whatever he may find unnecessary.

Factors Involved.—The principal factors entering into the calculation of the power required on any tramway route are:—

(i) The weight of the cars.
(ii) The speed to be maintained.
(iii) The density of service.
(iv) The gradients to be negotiated.
(v) The curves to be encountered.

In addition, the likelihood of rapid growth of traffic has to be kept in view, and emergency demands, such, for example, as crowds due to sporting events, have to be carefully considered and the necessary allowances made.

A convenient method of procedure is to use squared paper—preferably cloth-mounted for durability—divided in millimetres. A reddish-brown colour will be found much less trying to the eyes than blue or green. On this, taking as a convenient scale 1 centimetre to a furlong, the line is marked off, and the positions of the cars for maximum service in both directions laid down upon it. The length of the route, the speed scheduled, and the number of cars per minute allow of these positions being found without difficulty. At each of these points the current taken, as influenced by gradient, curve, &c., is noted. If now the line be regarded as a system of parallel forces, it is a simple matter to combine them to a single resultant. The point of action of this resultant is the load centre of the route, and marks the most economical position of the feeding point; while its value (the sum of the various car-loads) represents the maximum ampere demand. The whole system should be so analysed, route by route.

An analogous construction determines the most economical situation for the power-house. For this a skeleton tracing of the network, conveniently taken off a six-inch Ordnance map, will be found most suitable, and on it the positions and values of the various load centres are marked off. These are joined up in pairs—the order in which they are taken is quite immaterial—and the joins divided inversely as the loads, thus giving a series of resultants. These are joined up in pairs as before, and the joins again divided inversely as the resultants. Finally, a single point is found, and this point is the situation required.

Practical Example.—The following practical example will, it is hoped, make the method of procedure clear.

On a proposed line to a pleasure resort on a hill-top near a large city, a one-minute car-service at an average out-and-home speed of fifteen miles per hour was to be maintained by cars weighing 12 tons, equipped with two 30-horse-power motors. The length of the road was two miles.

As a preliminary, a table is constructed giving the current in amperes, the horse-power required, and the maximum speed in miles per hour for the car in question up various gradients.

Per Cent Gradient.	CURRENT IN AMPERES.		ELECTRICAL HORSE-POWER.		MAXIMUM SPEED, MILES PER HOUR.	
	Series.	Parallel.	Series.	Parallel.	Series.	Parallel.
0	14.0	28	9.38	18.77	7.4	17.4
1	19.0	38	12.72	25.45	5.96	13.52
2	23.5	47	15.75	31.5	5.15	11.9
3	28.0	56	18.75	37.5	4.6	10.8
4	32.0	64	21.4	42.8	4.22	10.01
5	36.0	72	24.1	48.2	3.92	9.44
6	40.0	80	26.8	53.6	3.68	8.76
7	44.0	88	29.5	58	3.47	8.54
8	48.0	96	32.3	64.6	3.28	8.16
9	52.0	104	34.85	69.7	3.12	7.94
10	56.0	112	37.5	75	2.98	7.56

From the Ordnance map we find that the starting-point of the route proves to be 147 feet above sea-level, and the terminus 556 feet; there is thus a rise of 409 feet in 2 miles, giving an approximate up-gradient of 4 per cent on the average. From our table we find that full attainable speed on a 4-per-cent gradient is just over 10 miles per hour; consequently on the return journey a speed of 20 miles per hour will have to be maintained to obtain the scheduled out-and-home average of 15 miles per hour.

At 10 miles per hour a car covers $\frac{1}{6}$ mile in one minute; hence, as we have a one-minute service to deal with, we mark off along our line intervals of $\frac{1}{6}$ mile, giving, on the outgoing journey, thirteen cars in motion at the

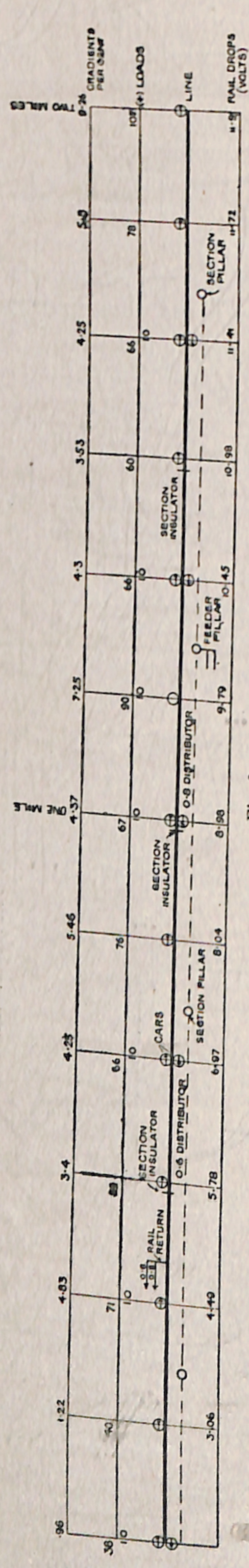


Fig. 82

same time. On the cityward run the speed is 20 miles per hour, hence our intervals are $\frac{1}{3}$ mile, and we have six cars inward bound in motion at the same time. It is to be noted that one car only is conceived as at the terminus, outgoing and incoming runs being regarded as one continuous movement.

From the route survey we find the gradients, &c., at the various car positions, and the corresponding amperes taken to be as in fig. 82; a total of 884 amperes for the uphill run. Theoretically, the inward-bound cars will take no current, as we find they are running downhill all the time; actually, we shall do well to credit them with 10 amperes each for lighting and contingencies. This will increase the maximum demand to 944 amperes.

Regarding the various amperages as a system of parallel forces, we find them equivalent to a single load of 944 amperes at a distance of approximately 6500 feet from the commencement of the line. The point so determined is the load-centre of the route, and is, from a power-supply point of view, the most economical situation for the feeding-point.

To ascertain the load-centre of a system, let us take an imaginary diagram of a network (fig. 83). The figures represent cars; a unit which it is sometimes convenient to use as an alternative to the absolute value of the loads in amperes.

On the route A G, I represents the position of the load-centre apart from the extra demand at K, owing to sharp curves there, equivalent to three cars. From I to K is 1500 yards; loads at I and K are 12 and 3 respectively; hence they are equivalent to a single load L equal to fifteen cars, situated 300 yards from I and 1200 yards from K—obviously so, since the moments of I and K about L are equal; 300 × 12 being equal to 1200 × 3.

Proceed now to join up the various load-centres in pairs in any convenient order, and divide the joins inversely as the loads; obtaining in this way R from L and Q; S from M and P; T from S and O, and finally V from T and R. The last-found point is the load-centre of the system as a whole, and marks the ideal situation for the power-house from the point of view of the economical supply of current. In our diagram it has accidentally come upon one of the lines of the network; but it is entirely in the natural order of things that the ideal site found may be not only off the route, but an impossible one from considerations of amenity, cost of land, want of a cheap water-supply, poor facilities for the delivery of coal, machinery, &c. A compromise has then to be effected, carefully balancing all the various pros and cons. Generally speaking, cheap water and fuel supply will on the whole prove the deciding considerations, despite the enhanced cost of the cables and extra lost watts which may be involved. Let it, however, be clearly kept in view that material departure from the ideal load-centre is apt to issue in an unsuspected increase in cable and power costs.

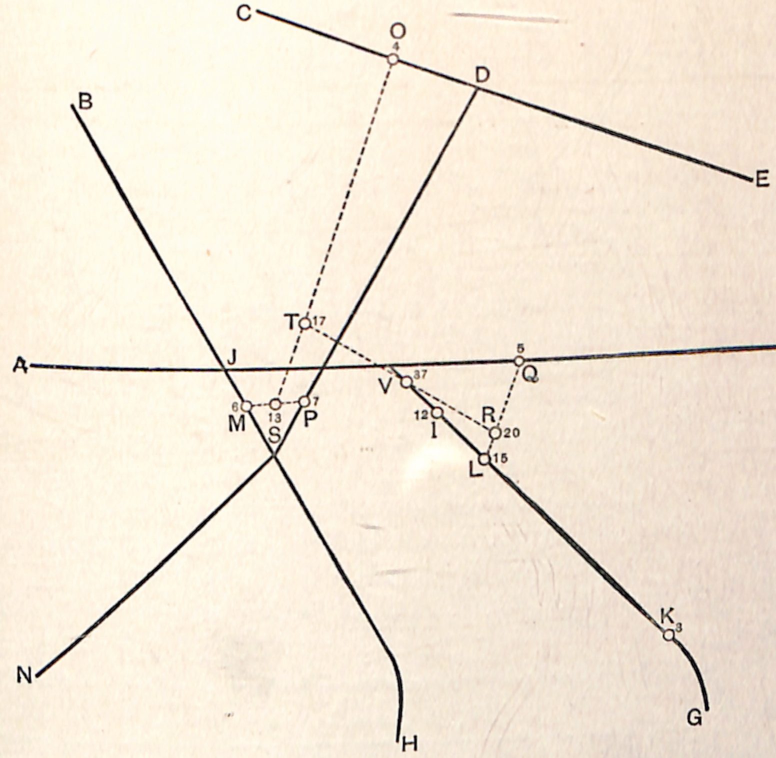


Fig. 83

Positive Feeding Arrangements—Simple Lines.—It is almost universally the practice, even on single lines, to use two trolley-wires, and to sectionalize them in order that, so far as possible, breakdowns due to mechanical causes or to failures of insulation in the overhead conductors may be localized and dislocation of the entire system prevented. In the British Isles this sectionalizing is obligatory, the trolley-wires being divided up into lengths of half a mile.

It is a safe plan, if somewhat of a counsel of perfection, to regard the trolley-wire as a reservoir of energy for the cars to be kept full by the cables, rather than as forming an integral part of the feeder system proper. Cases arise, however, where this cannot be done, and where the conductivity of the trolley-wires must enter into our calculations. This is particularly the case in simple lightly-loaded routes, to which, indeed, it is alone properly applicable. One method of effecting this is to tap the feeder in at each section insulator, thus feeding the overhead wires at either end of the sections (fig. 84). This no doubt utilizes to the fullest advantage the trolley-wires as a portion of the supply circuit, and in addition allows of a faulty section of cable or overhead work being cut out without permanently interrupting the supply to the remainder of the line; but it is not free from serious drawbacks. The extra switches and trolley-feeders are an undesirable and expensive complication, and the potential at the cars will be anything but constant and uniform; but the chief objection to this arrangement is that, as a glance at the diagram will show, a single fault in overhead work or underground cable will throw the whole line dead from end to end, and that locating and clearing the faulty section is likely to prove a lengthy process—and in tramway work it is most emphatically true that time is money. The gain due to the conductivity of the trolley-wires is discounted by the extra expense and complications of switches and cables involved, with the inevitable possibilities of dislocations of service; by the bad distribution of potential, and by the chances of long and costly delays.

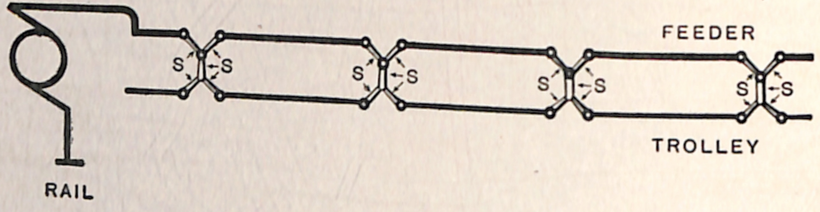


Fig. 84

It is a distinct improvement to feed each section at one point only, and that the middle. This does away with just half the number of trolley-cables and switches necessary in the system described above, and with them eliminates at least half the chances of mistakes and breakdowns due to a somewhat vulnerable portion of the power-supply. The potential at the cars, too, can be made more satisfactorily uniform (fig. 85).

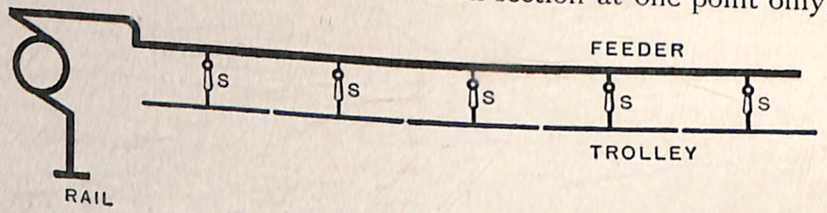


Fig. 85

Complicated Networks.—In a system of any size, however, the simple method of looping a feeder into a number of section-pillars in series would become wholly impracticable, and a different manner of arranging the lay-out becomes necessary. We have to provide a number of feeding-points, whence properly-graded distributors are run to other section-boxes, and which are methodically joined up to other feeding-points by interconnector cables.

On any particular route the load-centre as previously determined is, generally speaking, as was said, the best spot at which to place our feeding-point. It may chance, however, that the load concentrated there may be such that it is preferable to resolve it into two or more components, located at other points along the route. Or again, if our feeding-point is to interconnect (as it ought) with another or others, considerations of cable economy may decide us to locate it nearer a junction of routes than we should otherwise do, rather than run the interconnectors out to the theoretically best position—which, as a matter of fact, is really only an approximately ideal location. Then, we may find it good policy to run a feeder directly to some important junction, where traffic is dense and where seconds count as silver in an interruption of supply. Or we may have some severe curves or sharp gradients to contend with, and these may decide us to locate our feeding-point there. Any particular case must be studied on its merits with due regard to all the factors coming into the problem.

From our feeding-points distributors convey the current to section-boxes located midway of the half-mile sections of the trolley-wires, which are fed by cables passing up the poles. Interconnectors, as has already been said, should be arranged for, for the double purpose of allowing of the lines being fed from other feeding-points should a feeder or distributor break down, and of permitting of their being assisted on rush days by feeding them from two or more cables in parallel.

A system so arranged allows of a fault being rapidly located and cleared even in a complicated section, provided the job is gone about in a systematic manner; and, even should it be necessary to bridge over the section insulators on an outlying line, owing to the failure of a distributor or feeder where there is no available interconnector, the time necessary to do so, given the smart emergency men and motor tower-wagons and properly-designed section-insulators one expects on a large, up-to-date system, is not serious. Paralleling the trolley-wires at feed-ears and section-insulators ensures their most efficient use. No doubt a fault on the one must then inevitably involve the other; but considering that the wires are unavoidably paralleled at every cross-over or turnout, it is difficult to see the validity of the objections raised to the practice.

Determining Cable Areas.—In determining the areas of the cables we have to use, we aim at minimizing our voltage-drop and at securing as much as possible a uniform potential at the cars. This latter condition is of really capital importance; fluctuations of light in a car are most trying to the temper, and passengers will be found to complain far more bitterly about such irregularities than of variations in speed.

Lord Kelvin's law, that the cost of the units of energy wasted as I^2R losses in a cable should equal the interest upon its total cost, installed, is no doubt formally true; but, like many other generalizations arising from a number of particulars, these particulars are, in our case, so very difficult of determination that the law is practically inapplicable. For in tramway work, unless in the very exceptional case of supply from a large number of separate stations, we find ourselves compelled, to attain our aim of uniform potential and minimum loss, to design our cables not for their current-carrying capacity, but for their voltage-drop; which should never exceed 10 per cent from bus-bars to cars.

Limits of Direct-current Feeding.—For distances radiating up to about 5 miles on average roads, feeding at a potential of 550 volts from a single direct-current station is quite feasible; but beyond such a radius, in a system of any size, sub-stations fed from a central power-house with high-tension alternating current should be employed. Over-compounded rotaries will be found the best all-round form of converting machinery, not only on account of cheapness and efficiency, but from their valuable property of condenser-effect in improving the power-factor of the alternating-current system. It is not, however, good practice to multiply the number of these sub-stations unduly. A single station of decent size costs much less than two others of half its capacity; while the expense of attendance is the same in each. In comparing the cost of extra feeder cables as against an extra sub-station, the cost of the cables installed complete, together with their I^2R losses, upkeep, and depreciation, must be capitalized against the capitalized cost of the station, erected complete, together with insurance, upkeep, depreciation, stand-by charges, running expenses, and I^2R losses in the smaller cables required; keeping in view, too, the future developments of the district. Too much power, however, ought not to be concentrated in a single station, else the negative circuit will involve trouble and expense in preventing electrolytic mischief.

When balancing the pros and cons of cables or station it should be borne in mind that moving machinery is necessarily more liable to breakdowns and to the influence of the personal factor than are cables, and that the station will certainly involve more interruptions to service, and consequent delays and loss of revenue.

Use of Positive Booster.—In small systems, or on long lines where there is a peaky load, excellent results may be obtained by the use of a positive booster. If, however, the load is going to be continuously heavy, it is much better to put in a heavier feeder. The first cost of the booster-set—which need only be of sufficient capacity to deal with the number of amperes of the feeder's peak-load at the rise of voltage desired—will certainly be considerably lower than that of the extra cable; but, on the other hand, the watts lost in the former will greatly exceed those lost in the latter. The loss of power occasioned by the booster itself, coupled with the very heavy drop which a feeder will certainly need to have to warrant the use of a booster at all, mounts up very rapidly, as will be shown from the following example:—

Suppose it becomes necessary to transmit 310 amperes a distance of 4 miles from the generating station, and it is decided to boost this current to the extent of 100 volts, and that the potential at the end of 4 miles is to be 440 volts. It is assumed that the full value of the over-compounding of the generator is utilized, giving 550 + 100 = 650 volts at the station. The number of kilowatts furnished by the booster will be 31, and the combined efficiency of booster and motor will vary between 65 and 85 per cent, according to the size of the booster. In this instance we will assume 80 per cent. There will therefore be lost in the booster 7.75 kilowatts. The potential in the line will fall from 650 to 440, or 210 volts, which, with 310 amperes flowing, will absorb 65.1 kilowatts. The total loss will therefore be 72.85 kilowatts. Assuming this loss to continue for an average of 15 hours per day, which is about usual for tramway practice, we have a total loss of 398,853 kilowatt-hours per annum. Assuming this to cost 1*d.* per kilowatt-hour, which is a fair price for power as generated by a tramway station of average size, the total value of the loss in feeder and booster will be £1661 per annum. The upkeep of the booster and motor will bring the total cost up to at least £1670 per annum.

The size of feeder necessary to transmit 310 amperes for 4 miles with a loss of 210 volts will be 0.25 inch. The cost of this cable, with paper insulation, lead-covered, exclusive of laying, would be about £1896. The cost of the booster and motor, of say 31 kilowatts each, would be (at £5 per kilowatt) £310, making a total of £2206 of capital, upon which the interest at 5 per cent would be £110, or a total annual cost of £1780. To transmit this same amount of current, and maintain 440 volts at the end of the feeder without the aid of the booster, and assuming that the full extent of the 10-per-cent overcompounding is available, would require a feeder with a sectional area of 0.5 square inch, costing, with the same grade of cable as above, £3440, the interest upon which, at 5 per cent, is £172. The loss in this feeder of 105 volts while transmitting 310 amperes would be at the rate of 32.5 kilowatts per hour, and figured for the same number of hours would come to £741 in the course of a year, or a total of £913.

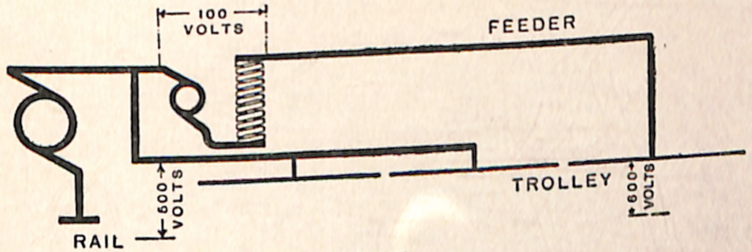


Fig. 86

From this it will be seen that, although the booster system is cheaper in first cost, it is much more expensive to operate if the load is constant; but if it is necessary to provide for a maximum load of about five times the average, the booster will be found useful. Boosters are generally arranged as motor-generator sets, and the connections of one for positive work are illustrated in fig. 86.

The Negative Circuit.—The negative circuit in a tramway is formed of the rails and any negative cables which it may be found necessary to install; and this is a most cogent reason why a track should be led back to every station or sub-station, rather than that the rail ends should be connected to the negative bus-bars by long cables. Apart altogether from the convenience of the rails for the quick delivery of material, &c., which has only to be mentioned to be immediately appreciated, steel is obviously much cheaper than copper. Self-evident though the truth of all this is, it does not always seem to be remembered by the designers of traction layouts.

Negative Feeders.—Rail-return cables should always be boosted if they are used at all. If they are not, their expense is out of all proportion to their usefulness. A booster for such work is with advantage carried on an extension of the rotary or dynamo shaft, and is so arranged that the line current of one or more feeders supplying the area in which the negative feeder or feeders are connected to the rails is used to excite its field, while the negative current passes through the armature. A self-regulating action is thus introduced. When there is a heavy demand upon the feeder the booster plainly acts more energetically in sucking back the current from the rail; when the demand is light the action diminishes in proportion.

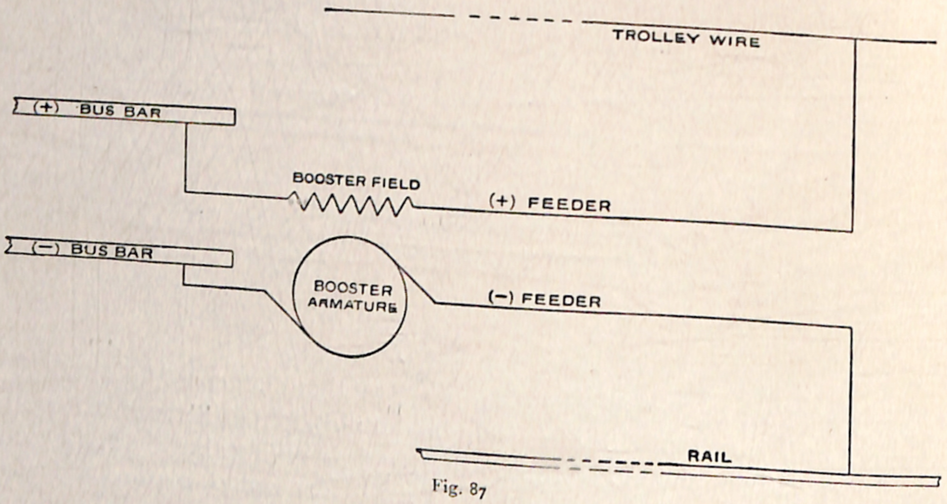


Fig. 87

Arrangements are made whereby any feeder may be connected to any booster-field and any rail-return to any booster-armature, and whereby the portion of current flowing in the field can be varied at will. The boosting should be so regulated that the potential at the rail points, as shown by the test-cable voltmeter, is just about zero. Overboosting will introduce as many drawbacks as underboosting; the formation of an area whose potential is below zero creates a sink of current, towards which a flow is set up along any and every underground conductor with disastrous results in the way of electrolysis.

Board of Trade Limit.—By the Board of Trade regulations the potential difference of any part of the rails above or below any other must never exceed 7 volts, and with this as our limit we have to determine the points at which our negative circuit shows a high voltage, and where we have to connect our negative feeders to the track.

Determining Boosting-points.—Now at the outset we are met with a difficulty. Since the rails, especially in damp climates and in towns, are more or less perfectly and continuously earthed, it is obvious that the current they carry will not confine itself to them, but will tend to diffuse itself into the earth all along their length, returning, of course, to the rails at the station end. Probably had we any means of rendering visible the sweep of the current streams we should find them on the whole pursuing curvilinear paths, something like the lines of force between the north and south poles of a bar magnet. The analogy, however, is very rough: negative nodes appear at different points of the line, and only one who has carried out tests on a tramway network can realize how unexpected and inexplicable are the complicated and capricious variations of track potential. We shall, however, be erring on the safe side if we regard our rails as forming an insulated conductor along which the current flows without leakage back to the station and along which the potential rises in proportion.

Practical Example.—Taking as a concrete case our extension, we shall assume it laid with four rails, efficiently bonded and cross-bonded, weighing 100 lbs. per yard. For our present purpose it is sufficiently accurate to take the resistance in ohms per mile of such a track as equal to 0.01. With our outgoing and incoming cars spaced as before we have plainly the currents marked flowing in the rails; and recollecting that voltage drop = I R, the potentials at the various car stations will rise (as shown) from 1.57 volts at the beginning of the extension to 11.9 volts at the terminus (fig. 82). Our maximum voltage is 4.9 above the Board of Trade limit; hence we must reduce the voltage of our rails to zero somewhere between stations 2 and 3. The rise between 2 and 3 = 1.29 volts, the distance being $\frac{1}{6}$ mile. Difference between the excess voltage and that at 2

$$= 4.9 - 4.49 = 0.41;$$
$$\therefore 1.29 : 0.41 :: 0.167 : x,$$

whence $x \doteq 281$ feet. The point to which, therefore, we have to carry our negative feeder is situated a little over 2000 feet from the commencement of the extension.

The current to be dealt with = 775 amperes, and the area of the cable or cables to be used will depend on the distance the station is away, and on the range of the booster. We may if we choose, of course, break up the load into components should that seem the better plan. For definiteness, suppose our station is 1.4 miles away, and our booster maximum 50 volts negative; we find, using two 0.8-square-inch cables in parallel, a drop of 28 volts with a current of 775 amperes. This, added to 4.9 volts, gives us a total drop to be overcome of nearly 33 volts, which our boosters can readily deal with. As has been said, however, we have acted on an assumption which makes our conditions much more unfavourable than they are in reality, and we should not find ourselves wasting anything like the amount of units represented by 775 amperes at 33 volts.

Installation of Tramway Mains—Overhead Feeders.—Tramway feeders may be installed in various ways: they may be run overhead; laid directly in the earth; laid solid, or drawn into ducts.

Overhead feeders are certainly, as a rule, rather unsightly, though their ugliness may be greatly minimized if a little consideration is given to appearances. Neither span carriers nor insulators need necessarily be ungraceful, and if a stranded galvanized-steel span be strained between the insulators and the conductor proper suspended by hangers of graduated length from the catenary so formed, the result is by no means unpleasing. For a moderate service, especially where the ground is insecure, this system deserves serious consideration; it is cheap, and, if properly installed, it is extremely unlikely to go wrong. The pole insulators alone should be depended on for insulation, the cable needing only to be weather-proofed. The conductor may with advantage be of aluminium, as modern methods of mechanical coupling, cast welding, or electric welding have largely done away with jointing troubles, which were the main stumbling-block to its use. Great care must, however, be taken to protect any joint made between the aluminium core and any dissimilar metal (such as a copper or brass lug) from the air by a thick coating of insulating paint, else trouble from local electrical corrosion will ensue.

Direct-laid Cables.—If overhead feeders are not to be used, and the ground is unsound from any cause—from mineral workings, for example—laying the cables directly in the earth presents advantages when the cables are only a few in number. For such a purpose plain lead-sheathed cables should be absolutely barred; the lead will certainly fail under the tensions and compressions it will undergo, and in such situations deleterious water is very often met with. Armoured cables must be used, and in bad spots a special type is necessary if any satisfaction is to be anticipated. For this latter purpose it is suggested that the specification sketched should be followed. The lead should receive a sheathing of vulcanized bitumen, say, $\frac{1}{16}$ to $\frac{1}{8}$ inch thick, to protect it from chemical and electrolytic corrosion, and upon this should be applied an armouring of galvanized-steel wire, thoroughly compound; this strengthens the cable enormously against tensile stresses. Over the steel wires two compounded Hessian tapes are applied, and on these as a bedding, two steel tapes, galvanized and compounded, applied so as to break joint, give protection against transverse pressures, blows, or direct crushing; the wire layer beneath protecting the lead from any pinching action of the strips. Finally, two compounded Hessian tapes are applied over all. Each step of the serving and armouring is followed by a bath of compound which cements the whole into a solid mass. The standards of the British Engineering Standards Committee should be followed for the thicknesses of serving, wires, and tapes. Such a cable, laid in a sinuous line from side to side of a good broad trench, and bedded in sand, will probably be found to give the best results in districts subject to subsidences. It is both cheaper and more reliable than the solid system in such situations, and is at least equally reliable as ducts. A word of caution may be seasonable here. The cable is extremely messy to joint, and jointers being only human are apt to get rid of the sticky stuff by the easiest means possible, and to neglect bonding the wire armouring properly over the joint. A covering of bricks, tiles, or creosoted wood is advisable some distance above the cable, as conveying a warning to workmen opening up the ground. No armouring will stand the fair blow of a sharp pick wielded by a strong man.

Solid-laid Cables.—Solid-laid cables, when the work is carefully done, the ground beneath sound, and the traffic over the cables not too heavy, undoubtedly give excellent results in the way of reliability; but the system shares in an enhanced degree the disadvantage of inflexibility to extension common to all buried work. The chases in which the cables are laid may be of almost anything; iron, stoneware, asphalt, wood, are all used. In all except the third-named, insulating bridges to support the conductor out of contact with the bottom are required, and it is important these should be of suitable material. Wooden bridges are fruitful sources of trouble, chemical and electrolytic, and should under no circumstances be used. Hard stoneware, thoroughly "cooked" in hot compound until perfectly coated, is a suitable material, but the best of all is hard bituminous composition; the surface amalgamates perfectly with the filling compound, while the body of the bridge preserves its rigidity.

In the Howard system the troughing being of asphalt, itself an insulator, no bridges are required. The conduit is supplied in pieces about 5 feet long, a thin sheet-iron former supporting the asphalt which projects a little at either end. The sections are burned together into a continuous length and the joints smoothed off with suitable jointing-irons; the cable run in with melted compound, and the trough topped off with asphaltic concrete, applied hot and polished down smooth with heated moulding-irons to form an impervious domed covering welded on to the asphalt sides. The results are very good indeed, but the system is expensive in materials and labour.

Earthenware chases give good results, but under heavy traffic failures at the joints have been noticed; an observation which equally applies to iron troughs. For all-round work, stout creosoted wood troughing of generous size gives very satisfactory results, with the added advantage of cheapness.

Filling Compound.—For filling-in nothing is superior to *genuine* bitumen; but much of what is offered for sale has no proper right to the name. If procurable, that from Venezuela is best. It is of low specific gravity, and so it goes far, and it is exceedingly pure. It is always well to purchase a pure article and load it to the desired degree oneself; there is no advantage in buying dirt under a fancy name and paying carriage upon it; it can, as a rule, be procured on the spot. A composition of 60 parts (by weight) of Venezuela bitumen, 40 parts of finely-ground limestone or whinstone, and 5 of pure acid-free petroleum residue, well melted and stirred up together, will be found to excel in toughness and dielectric strength. It is, however, expensive, running to £5 or more per ton. Pitch compound, if properly made up from good materials, gives excellent results, and is, of course, very much cheaper. Only the best gas-works pitch must be used, and with it and the tempering oil stringent guarantees as to freedom from acid or alkali should be insisted on. Blast-furnace pitch is quite unsuitable, physically and chemically, and should never be used. Solid-laid cables, like those laid directly in the earth, should have a covering of some sort some little distance above them to warn excavators of their presence.

A Duct System Preferable.—For a route joining up fixed termini, on which the power demand can be determined once for all and cable provision made accordingly, the solid or direct-laid system will give satisfaction; at least, until a cable breakdown occurs, when the admiration for it is likely to be somewhat qualified before the repair is effected; for it is a weak point with the solid system that wet weather makes satisfactory laying or repairing a very dubious business indeed, and in the uncertainties of British weather a breakdown is just as likely as not to take place in rain; while both involve a troublesome fault-locating test and laborious and expensive breaking up of the roadway. Taken all round, for tramway work generally by far the most suitable way of installing cables is to draw them into ducts.

Flexibility.—The truth of this is readily appreciated by a little reflection. In laying out a route one can afford to be—and ought to be—liberal with the provision of ducts, since an extra way or two adds quite a small amount to the total cost per mile; and only enough copper for the immediate needs of the road requires to be drawn in. Should the traffic grow, more or larger cables can be installed without any trouble.

Reliability and Convenience for Repairs.—In unsound ground, again, properly-laid ducts are much more reliable than the solid system, and are very little if anything behind the direct-laid, while in roads subjected to heavy traffic the cables are better protected from crushing and shearing. In fault location, again, even if nothing but so rough a method as cut-and-try is used, the work is easy in ducts. For example, take a cable 20,000 feet long, with manholes averaging 400 feet apart, one cut midway narrows the fault to within 10,000 feet, a second cut midway of the faulty half reduces the limit to 5000 feet, a third to 2500, a fourth to 1250, a fifth to 625 feet, a sixth to 313, or less than a manhole stretch. At most, then, four extra cuts have been made—two is the minimum in any repair unless the fault was *in* a manhole, which inspection would have shown—a short day's work for a jointer and his mate. This compares favourably with the expense of making a single opening down to a solid or direct-laid cable. The fault located, hauling out the faulty stretch, hauling in a new one, jointing it up and making it alive, are matters of a very short time.

Contrast with Solid- and Direct-laid Systems.—Contrast this handiness and flexibility with the unwieldiness and rigidity of its rivals. With either a direct- or solid-laid system, when laying out a line one is faced by the dilemma of burying a mass of expensive but unproductive copper, interest on the cost of which will have to be paid no matter what happens, for the benefit of a problematical increase in load in the more or less distant future; or of making up one's mind to have to dig up the roadway again to lay additional cables when the demand necessitates them, incurring in so doing not only heavy expense and a very real risk of damaging those already in the ground, but the merited resentment of the lieges. As for locating and repairing a fault on a solid- or direct-laid cable, it is, as has been hinted, about as disagreeable a task as could well be selected. Drawn-in cables, provided the ducts and manholes are good in material and workmanship, the laying of the cable properly done, the jointing workmanlike, the bonding efficient, and the negative boosting skilfully looked

after, will be found to last a very long time indeed without breaking down from corrosion of their sheathings, while solid- and direct-laid cables are by no means entirely free from such accidents as electrolysis.

Comparative Cost.—As to cost, certainly up to six cables, ducts and manholes are the most expensive; but above that number the position is reversed, and the figures become more and more favourable to the draw-in system the more cables there are to be installed. Indeed, one rapidly reaches the limit one can lay direct or lay solid, even if one is prepared to go the length of absolutely underpaving the street with cables; for to arrange a solid system in tiers would be a measure only to be taken in extremely exceptional circumstances. With a duct system, on the other hand, there is no difficulty at all in arranging for fifty or more cables in a single manhole.

Ducts—Metal.—Ducts may be, and have been, made of almost anything. For very shallow work, such as, for example, a bridge where there is but little available cover, steel steam-pipes treated hot with Angus Smith's composition, and united with ferruled joints well screwed home, bedded in strong fine shingle concrete, are about the best. They are certainly expensive, but considering their great strength and the short distances for which they have to be used, they do not add seriously to the total cost of a line. They must, of course, be quite free of "fins" inside, and the sharp edges at either end must be smoothly rounded off from the inside in each length. Mannesmann or similar thin-walled steel tubes, jointed with spigot and faucet, lead-caulked, are certainly cheaper, lighter, and more easily handled, while being well adapted from their treatment to resist corrosion. Though otherwise entirely suitable for carrying cables they are necessarily not so strong as steam-pipes, and in shallow work this extra strength is a decided advantage. Cast-iron pipes from their brittleness are for shallow work inferior to both. Whatever metal is used, the ducts should be in perfect metallic contact end to end with one another throughout their length, and they as well as the cables should be soundly bonded to the manhole earth-plates to minimize electrolytic troubles. For the general run of the ducts metal presents few, if any, advantages; it certainly does not prevent electrolysis. If any iron ducts are to be used the best quality only should be considered, and the pipes should be properly and severely tested for straightness and internal smoothness. Too often it seems to be imagined that any rubbish rejected by a gas or water authority's inspector, and so purchasable from the foundry at a price approaching that of scrap, is good enough for electrical mains work; though the disastrously destructive effects on the cable sheathings of internal constrictions, blisters, core-pins, and all the array of obstructions workmen expressively name "rat-catchers", might be foreseen.

Cement-lined duct has been largely used; but though satisfactory enough when carefully laid, it is not so good as some other forms. It consists of a thin riveted shell of wrought iron, lined to a thickness of $\frac{3}{8}$ inch with Rosendale cement, and carrying at the ends small cast-iron spigot and faucet rings. The cement lining has been found to act deleteriously on some makes of bitumen-sheathed cables, while the very short joint is a decidedly weak spot. It tends with careless laying to gape or even to allow the duct to get out of alignment, and so to admit surface water; and should the ducts be bedded, as they may be when contractors of the baser sort are left to their own devices, in engine ashes dusted over with cheap cement, the seepage which percolates through into the ducts will be found to corrode away the sheathing of a lead-covered cable in a very short time indeed. The duct is in itself mechanically weak and easily injured, and its price is by no means low.

Stoneware.—The well-known square multiple stoneware ducts made by Doulton are somewhat troublesome to install in good alignment and free from cement in the joints, but when well laid are quite satisfactory. The material is strong and impervious, and a good point is that there is less friction with them than with those of round bore, and consequently a cable is pulled into them with less labour. The Sykes duct, made by the Albion Clay Company, is very good indeed; material and form are excellent and the duct is readily laid. The self-aligning Stanford joints, when well payed with hot rosin and tallow and driven home, are satisfactorily water-tight; while, if found necessary to do so, the conduit line can be easily conformed to a smooth curve. Labour is economized by using cluster-form ducts, but if the slight danger of a cable failure just at the duct joint burning out others, owing to the existence there of a small space where there are no barriers between the cables, be apprehended, single-way ducts can of course be used.

Ducts, whatever their form, should be purchased from a good maker. Numerous imitations of successful designs are on the market, but in few cases will satisfaction follow their use. A useful test, besides being a striking experiment, is to take a fragment chipped off a duct by a first-class maker and one from the imitation, and touch them simultaneously with ink; which in the one case will be found to remain on the surface, while in the other it flashes in an instant into the substance. If the two samples are dipped into water it will be found that the high-grade material will remain wet after the single immersion, while the inferior will have entirely absorbed the surface moisture three or four times from as many successive dippings. The undesirable qualities of a duct which depends on its glaze only to exclude damp while its body is absorbent of moisture need not be dwelt on. Stoneware, not earthenware, should be made a *sine qua non.*

Fibre.—Fibre duct, made of wood-pulp and a bituminous bond, is largely used and gives good results. From its lightness it is very easily handled, but it requires more concrete round it than does a stoneware pipe. Its cost, laid, is on the whole higher. It seems more "dead" to draw a cable through than does a stoneware duct, and under a severe pull with a cable too tight for it, its inner layers have been found to shell off, and the whole duct collapse and go to pieces under the longitudinal compressive stress, though bedded in concrete. On the other hand, when sleeve-jointed, surface water is well excluded; the duct itself cannot conduct electricity, nor can its substance mechanically injure the sheathing of a cable. It certainly is inflammable, in the sense that it can be made to burn; but it gives off so dense a volume of smoke that only with a good draft can its combustion

be continued. Ducts, whatever their material, should not be under 3⅛ inches in clear internal diameter, and should be laid with a very gentle rise from each end to the centre of the stretch to drain moisture into the manholes. There should be no sudden rises or falls of level, and no sag to produce an accumulation of stagnant water.

The side-walk is, of course, the preferable situation in which to put the cables, provided there are no cellars beneath it, but it is not often that the chance of occupying it exists. Generally speaking, other services have secured the option, and tramway cables have to be laid in the roadway; between tracks, or in the rag in single-track roads. If they are laid while the rails are being put down a great saving in duct-installation will be effected. Whatever their position, however, the cables ought to be kept at a minimum distance of 3 feet from the nearest point of the rails if this can be done. The bugbear of tramway cables is electrolytic corrosion. In a duct of non-conducting material, provided it be dry, there is no reason why a lead sheath should not last indefinitely, but dry ducts are very much the exception. Even if surface water is successfully excluded—and every effort should be made to do so, especially in towns—there is always a condensation of moisture going on. The slight varying temperature of the cables sets up an air circulation which draws into the ducts the humid atmosphere of the manholes, with a consequent deposition of water, apart altogether from and in addition to what is attracted to negative points of the lead by electrical osmosis.

Electrolytic Dangers.—Experiment indicates that in the case of a rail in a tramway track the potential gradient between the conductor and earth is so steep that practically the whole fall takes place in a very short distance, the slope then becoming so flat that at 3 feet away from the rail the potential difference over a considerable length has no readable value. Now, though it is an undoubted fact that electrolysis goes on with any difference of potential, no matter how small, a coulomb of electricity conveying a fixed number of metallic ions, whether its flow be 1000 amperes or 1 milliampere, it is plain that the time in which the mischief is done is influenced most vitally by the rate of flow. If, then, we keep our cables 3 feet away from the nearest point of the rails we shall very greatly lengthen their useful lives. It is a common practice, but a very bad one, to bond rails and cables together in every manhole. This is simply going directly towards trouble; for putting rails and sheathings in parallel makes both part of the anode of the great electrolytic cell, with a consequent tendency for the current to jump off at some point—a wet stratum, a large water main, &c.—where the rails and cables are positive to ground. For one or two manholes on either side of the negative boosting points, and at the station ends, cables and rails should certainly be efficiently bonded together, but haphazard paralleling-up throughout the network is quite wrong. The cables, however, should be properly earthed in every manhole, and a cheap and excellent connection can be made by burying below the level, and clear of the sides of the foundations of the manhole, 7 or 8 feet of clean old rail, rammed hard up with broken coke to ensure its keeping wet, and leading stout bonds from each into the manholes.

Testing.—The potential between rails and cables should be carefully studied under working conditions, and wherever the latter are found positive to the former, a bond or "drain-wire", to use the graphic American term, should be used to connect them together. A word of warning is necessary as to this testing. The readings are generally low, consequently the contact piece for touching the metallic sheathing of the cables or for exploring the potential around them must be of the same metal as the sheathing. If a copper, brass, or steel point be used upon or near the lead, the contact force of the dissimilar metals in the former case, and the different electropositive value of the exploring pole in the latter, will quite vitiate the results.

Manholes.—Between-track tramway manholes having to support very great weights, well over 100 tons in some cases, require to be strongly built. They need not be very broad, but should be of a reasonable length, as this very greatly facilitates drawing-in cables. It is an advantage to have the walls curved.

For a six-duct manhole on a straight run a generous internal size is 7 feet long by 5 feet wide at the centre, by 3 feet wide at the ends. The side-walls can follow a circle of 9 feet radius without the necessity of specially curved brick. The concrete floor should be 7 inches thick, smoothly finished off with a granolithic layer, and graded to a corner in which a sump covered with a grating should lead to the sewer by a trapped drain. The sump should never be in the centre of the manhole, as dirt speedily chokes it in such a position. A depth of 6 feet 6 inches from the street surface to the floor is ample. The walls should be 9 to 14 inches thick, soundly built of good brick, and the earth between the brickwork and the sides of the excavation firmly rammed up. Where the bonds from the old rail earth-plates come through the walls they should be well taped and compounded. In place of brick the manhole can, of course, be readily constructed in concrete, preferably reinforced.

Two light channel bars, size 2 inches by 1 inch, sunk 3 inches into the concrete floor and rag-bolted into the walls at the top, serve on either side to support by brass screws the large brass hooks in which the cables lie. These columns should not reach quite to the roof, to prevent vibration which might in time cut through the sheathings. For the same reason roof hangers should be absolutely barred, and the cables supported from the floor or walls only. A convenient situation for these channels is, in a manhole 7 feet long, 2 feet 6 inches from either end, thus supporting the cables at points 2 feet apart.

For heavy traffic the roof is best made of old rails, well bedded in strong concrete. Where traffic is light, ½-inch steel buckle-plates may be used; but cast-iron plates should be avoided as heavy, brittle, and unsatisfactory in every respect. The manhole frame, dust-pan, and cover should be cast in steel for heavy city work; for average traffic, however, cast iron of good tough quality is quite suitable. The cover may be round, oval, or square; the shapes named standing in the general order of merit. For general work the round is preferable; for small, shallow manholes the oval has some advantages; the square possesses no outstanding merits at all, and has a conspicuous demerit (which it shares with the oval type) of being liable to fall bodily into the manhole through careless handling. The portions of the covers which come to the street level may be filled with fine concrete or asphalt, or with jarrah blocks grouted in with hot pitch, or they may be faceted into small squares by deep grooves running at right angles to one another. The last is the cheapest, and is quite satisfactory. Efficient ventilation holes are essential, and the lifting holes should be carried clear through; pocketed holes are an abomination. All manholes should be regularly inspected, washed down, and kept clean and free from water. In laying off a new road where there is no sewer, it is an easy matter to run a pipe beneath the ducts from manhole to manhole, and even if it is necessary to run outfall drains quite a distance from the various lowest points it is well to do so, for soaking in water is bad for cables. Part of the equipment of every mains department should be an efficient pump. That illustrated in fig. 88 can be recommended with every confidence; it is simplicity itself, and almost the only part of it liable to wear out is the rubber diaphragm, which is readily renewed.

It is a great luxury to have the manhole faced with white brick, but is a most decidedly expensive one. Such a manhole as has been described above can be built in first-class style of the best materials at about £23 inclusive; while with white enamelled facing its price runs up to over £33.

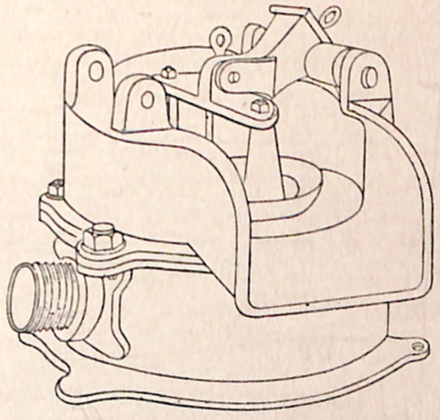


Fig. 88.—Diaphragm Pump

Draw-in Wires.—Draw-in wires should be of 12-gauge tough galvanized mild steel, but unless the ducts are going to be used in the near future it is not good policy to wire them. The wires rust away and cause trouble in clearing. To rod and wire well-laid ducts does not take long.

Rods.—Rods are better made of sound straight-grained ash or hickory than of malacca cane, on the grounds of efficiency, durability, and cheapness; there should be no need for the cane's sinuous properties if the ducts run straight or in such easy curves as alone should be permitted. Clearing-bells are for some mysterious reason generally made of gun-metal, which promptly crumples up in serious work; mild steel with a case-hardened lip is cheaper and incomparably superior. The screw couplings of the rods should be twice as long as they usually are.

Drawing-in.—Drawing-in is done with a powerfully-geared winch and strong jib. The rope is best made of plough steel, extra flexible, and should not be galvanized, as the process weakens it. Such a rope, 1½ inches in circumference, will be found to conform readily to a 6-inch winch barrel, and, though much higher in first cost, will outwear many 3½-inch manila ropes. It should be carefully attended to, of course; the fall as it comes off the barrel of the winch in drawing-in should be wound directly on a light iron drum, and in the yard the rope should be frequently passed through a bath of very hot motor grease. The eyes should be parcelled and wire-served, and left-hand spliced; and connection to the eyes of the cable clips should be made by swivels. The clips used should not be galvanized, and should only be purchased from first-class makers. The double-eyed pattern is the best. When put on the cable it is a good plan to cross-lash three pieces of draw-in wire through the eyes and over the outside of the clip, not so much for additional security of grip as to take up the wear against the duct and so increase the life of the clip. Clips ought to be kept well greased with hot lubricant. In preparing cable ends lead and copper should be wiped together into a solid mass about 6 inches long, so that the pull may come on copper as well as lead. If this is not done there is a great risk, especially with loosely-papered oily cables, of having the lead strip off, involving very often the scrapping of a large portion of the cable from damp, and in any case a great loss of time in backing out the damaged length. When ordering cable this extra length ought to be remembered; thus, the stretch between two manholes whose centres are 400 feet apart—a very convenient distance to take as a standard—one 7 feet broad and the other 5 feet broad, would be ordered thus:

"400 feet (= length between centres) +
6 feet $\left(= \frac{7+5}{2}\right.$, mean breadth of manholes) +
6 inches (= length for end wiping) +
6 inches (= jointing allowance);
total, 407 feet."

As the draw-in wire pulls in the rope it should draw in before it a strong duster liberally plastered with motor grease, and as the cable enters the duct it should be well lubricated. The grease should be of mineral origin, and guaranteed quite neutral. Soft soap should not be used, despite its cheapness, as its free alkali is deleterious to lead. All cables when finished off should be deeply stamped with their full designations.

Section Pillars.—Tramway section pillars should be as fool-proof as possible. Switches should be plainly lettered, and an explanatory tablet should be affixed to the inside of the front door. The telephone jack-box should have a positively-closing guard to keep out dirt. Anything not strictly necessary should be excluded. It does not make for efficiency to compel a man to fumble about amid a forest of switches. Fuses, reactance coils, lightning-arresters, &c., are quite right in their proper place, but that proper place is certainly not the section pillar. That illustrated in fig. 89 is a product of evolution and the survival of the fittest, and has been found to stand up to every test in the hard service of the Glasgow tramways. It is in three parts, bolted together, which amongst other advantages allows of the ventilation-ways at top and bottom being of a labyrinthine formation which defies the access of bits of wire to the interior, in the hands of mischievous or malicious persons.

The panel frame is built up of wrought-iron bars, and though not heavy is very strong. The switches are mounted, with pads of thin soft lead

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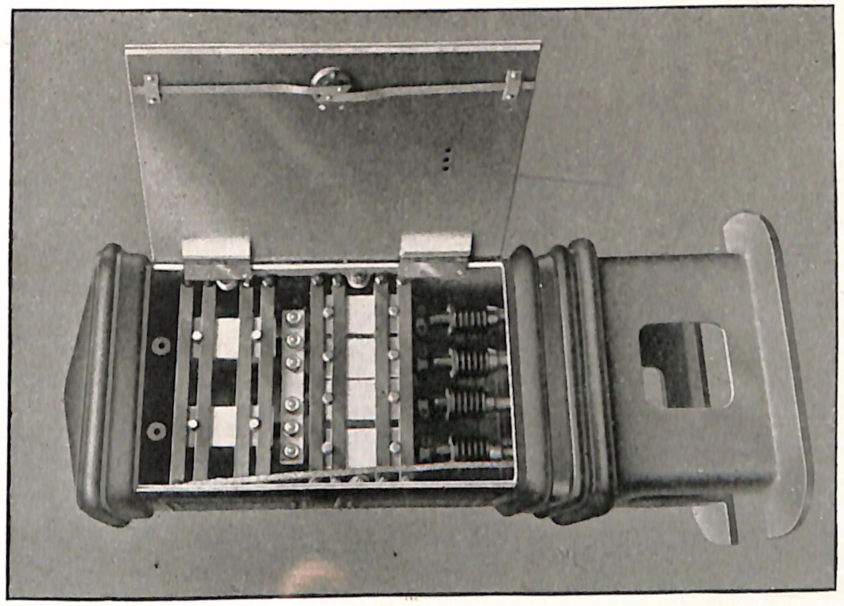
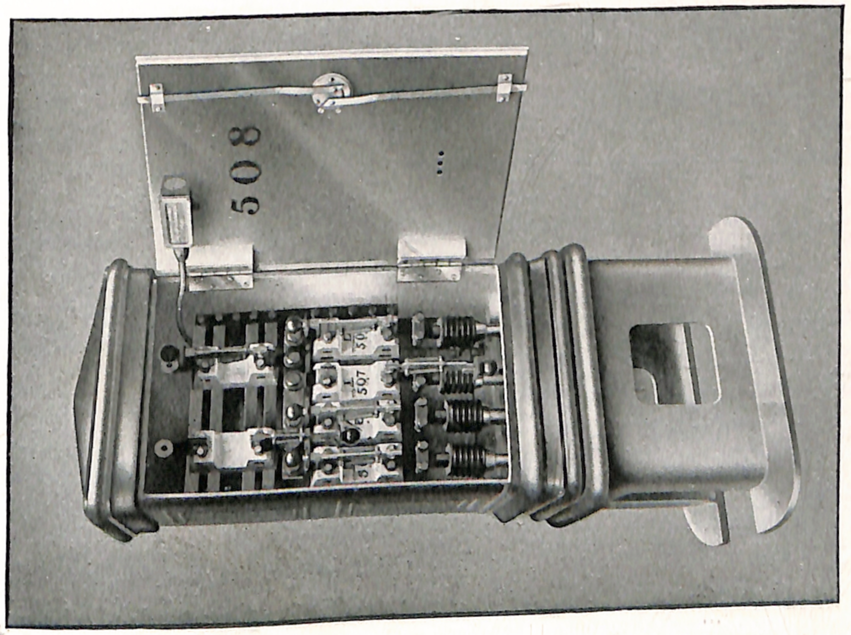


Switch Pillar (back view)

Fig. 89



Switch Pillar (front view)

interposed, on insulators of genuine porcelain, the insulation of which is independent of surface glaze. This mounting is done by causing the brass holding-down tap-bolts to screw into a tapped plate fitting loosely into an oblong hole in the body of the insulator, below the heel and jaw of the switch. When the switch has been adjusted to its correct position and the tap-bolts screwed home, the tapped plate is fixed immovably in its position by being run in with hot hard bitumen compound till the hole is quite full. Should it be necessary at a future date to replace the switch, this can be done by taking out the screws, with the certainty that the new switch—which has been bored off a standard templet—will fit into its position. All springs are genuine phosphor-bronze; steel rusts and brass breaks spontaneously. The insulators are secured to the panel-bars by a similar arrangement of lead pads to equalize irregularities, tapped plates and tap-bolts. All power cables terminate in strong glazed-earthenware heads, screwed into tail-pieces of cast solder, by which they are wiped on to the lead sheathings, the heads being filled up with bitumen compound. Care should be taken that the tail-pieces of the end connections are not made of white metal, the zinc in which will "poison" the solder used to make the joint, necessitating "burning out" the zinc with sulphur or scrapping the whole pot of metal. The telephone and test cables end in lead pot-heads.

Marble or slate or even wood panels are or have been used—the last, of course, only tolerable as a temporary makeshift—but none is satisfactory. Even when well bushed with ebonite, ambroin, &c., metallic stains appear, the insulation is poor, and the material and construction weak mechanically.

Trolley-wire Feeders.—Connection with the overhead work is made by means of flexible cables. Lead-covered rubber has been recommended for this work, but wire armouring is lighter and mechanically stronger, though care must be taken to turn the wires back and lash them soundly down when the armouring is taken off. Silicate-rubber sheathing is very satisfactory in every way. Rubber-insulated cables are confessedly subjects connected with which the unexpected often happens. A sheathing made by a good maker to a specification calling for 40 per cent of pure fine hard Para rubber proved imcomparably less durable than did one insulated with something which had practically no elasticity at all, and which, whatever its other ingredients, contained such a quantity of ground mica that on incineration a greyish skeleton practically the same size as the original remained. The wisest policy seems to be to buy under a guarantee from a good maker what he recommends as best.

For connections between the section pillar and the pole it is convenient to use two wrought-iron pipes, one above the other, of some 2 inches internal diameter. The mouths at either end are well rounded. They screw home into the pole, which is tapped to receive them, and pass by clearance holes into the pillar, inside of which they are secured by thin nuts, using, if the positions of pillar and pole render it necessary, shaped iron packing-pieces. The trolley feeders are left of such a length in the pillar that when connected up they are forced well back into the pole and so prevented from coming in contact with and chafing against the ends of their tubes. Where the cables come out at the top of the pole they pass through well-rounded brass bushes.

Points in Cable-construction.—Pole and section pillar are, of course, bonded to the rails. It is a distinct advantage to block up with clay the ducts leading into section pillars to prevent sweating from the damp air from the manholes condensing in the pillar in cold weather. It is also good policy, especially where extra-high-tension mains run in manholes, to coat the cables with a plastic fire-resisting composition to a thickness of about $\frac{3}{8}$ inch. For drawn-in work lead-covered, paper-insulated cables are practically standard. A serving of compounded jute over the lead is an advantage, but an armoured cable once drawn in is likely to stay there for good, and to resist all efforts to pull it out. For solid work vulcanized bitumen has advantages: the intense heat of the filling compound tends to stress a lead sheathing objectionably, and the shunting action of the metallic covering is a nuisance in inductive methods of fault-locating. In ducts, however, vulcanized bitumen is better avoided. Recent improvements are said to have eliminated its liability to suffer from contact with cement or lime, to liquefy in contact with coal-gas, and to saponify and soften from contact with alkalis, but it is well to err on the safe side. For tramway work the lead sheathing should be decidedly thicker than that recommended by the British Engineering Standards Committee, $\frac{3}{16}$ inch being a good all-round figure; but in all other respects the committee's specifications should be followed. Full details as to the manufacture and cost of cables will be found in Messrs. Coyle and Howe's book, *Electric Cables, their Construction and Cost* (published by Messrs. Spon), to which the reader is referred. Here it need only be said that in the hands of a good maker one is safe, the only stipulation—especially with foreign manufacturers—is the insisting on a stringent guarantee as to the absolute freedom of the dielectric from wood-pulp, as this very objectionable ingredient causes spontaneous disintegration of the paper.

Jointing.—Jointing should be done with a ferrule of pure soft copper, well sweated and compressed on to the core, and the insulation made up with rolls of impregnated manila paper, or, wholly or in part, with impregnated "linen" tape—almost all the so-called "linen" tape on the market is really cotton, but does well enough. A lead sleeve, soundly wiped on and filled up with compound, completes the job. Joint-boxes should be avoided, and only competent jointers able to wipe a sound lead joint should be employed. As a flux for copper, brass, or lead, nothing equals stearin; rosin is dirty and gives off a suffocating fume, while acid is, of course, quite out of the question.

For filling up the sleeve, pure hard acid-free paraffin wax gives good results despite its hygroscopic properties, provided allowance is made for its shrinkage before closing the upper pouring-hole. It has the advantage of being much cleaner than any other should the joint ever require remaking, and is invaluable in testing whether damp has got at the core or insulation of a cable. To do the test it is only necessary to pour smoking-hot paraffin wax over the suspected cable-end and to catch the

molten wax in a baler, which must be dry and hot. If now the contents of the baler be poured back into the kettle, the merest trace of wet will cause so sharp a crackling as to be quite unmistakable. Bitumen is an excellent if somewhat messy filler, but some highly-priced concoctions with fancy names froth up in such a fashion that one never knows whether or not a sound fill has been made. Whatever compound is used it is well to depend upon it merely for mechanical strength, making up the joint so well with the solid dielectric that it is equal to whatever stress it may have to sustain.

Telephone Cables.—Telephone cores for tramway work are better made with impregnated than with dry insulation, and should be of 660 volts standard. Despite their capacity, cables of this type, with cores of one wire, No. 18 S.W.G., give excellent talking over distances up to 14 miles; they are handy for testing purposes and do away with all the paraphernalia of air-compressors, &c., on the cables, necessary when the dry-core-air-space type is used. For jointing, paper tubes or cotton sleeving serve as insulation on the cores, which, if soldered at all, should be just touched at the ends of the twists. The test cores necessary to allow of the automatic recording of the rail potentials should be made up in the same cable. For them a strand of 3/18 or 7/20 S.W.G. is usual, and an insulation to withstand 660 volts.

Negative Cables.—Since by the Board of Trade rules it is necessary for the negative rail feeders to be regularly tested, they must be brought into disconnecting-boxes at the points where they are to be joined to the rails. Negative cables have an inherent tendency to break down through dampness, owing to the water-attracting phenomenon of electrical osmosis; consequently great care should be taken to fill up the end-bells with some absolutely non-hygroscopic substance. Bitumen compound will be found thoroughly satisfactory. Although they have only a pressure of a few volts to withstand, it is just as well to use 660-volt cable for rail-return work, to avoid the risk of having a lightly-insulated cable used in mistake for full-voltage work.

Miscellaneous Feeding Systems.—Various methods of three-wire feeding have been suggested, but for urban work the ordinary arrangement of overhead trolley and rail return is the cheapest and most satisfactory all round. For longer and for inter-urban traffic there is great promise in the use of single-phase alternating current. Laminated-field compensated series motors run excellently on low-period alternating current and on direct current alike. In Balton and Schenectady, New York, for example, the cars run on the ordinary direct-current system, while on the line connecting the two towns they operate on single-phase alternating current. A mere reference to the saving in distribution, owing to the use of high potential and to the fractional electrolysis caused, in comparison with the direct current, must complete all that can be said here about this most attractive and interesting method of working.

Testing.—To comply with the Board of Trade requirements the insulation resistance of the whole network must be regularly determined. By having in each station or sub-station a standard voltmeter, connected to the positive bus-bar and furnished with a lead long enough to reach any cable, the insulation resistance of the feeders, distributors, interconnectors, section-pillars, and overhead work in series can be determined by merely noting what deflection is given when the feeder-switch is touched with the terminal of the voltmeter lead. For, suppose the reading on the voltmeter when the lead is connected to earth is V_1, and the reading when the lead is connected to the cable is V_2, and that the resistance of the voltmeter is G, it is easy to prove that the insulation resistance of the object under test is

$$\frac{(V_1 - V_2)}{V_2} \times G \times 10^{-6} \text{ megohms,}$$

if V_1 and V_2 are in volts, and G in ohms. It simplifies calculations greatly to have the resistance of the voltmeter exactly 100,000 ohms. This test should be made every night, and a regularly detailed test of feeders and distributors, &c., made every month. Of course any suspiciously high readings (V_2) got during the nightly tests call for immediate investigation.

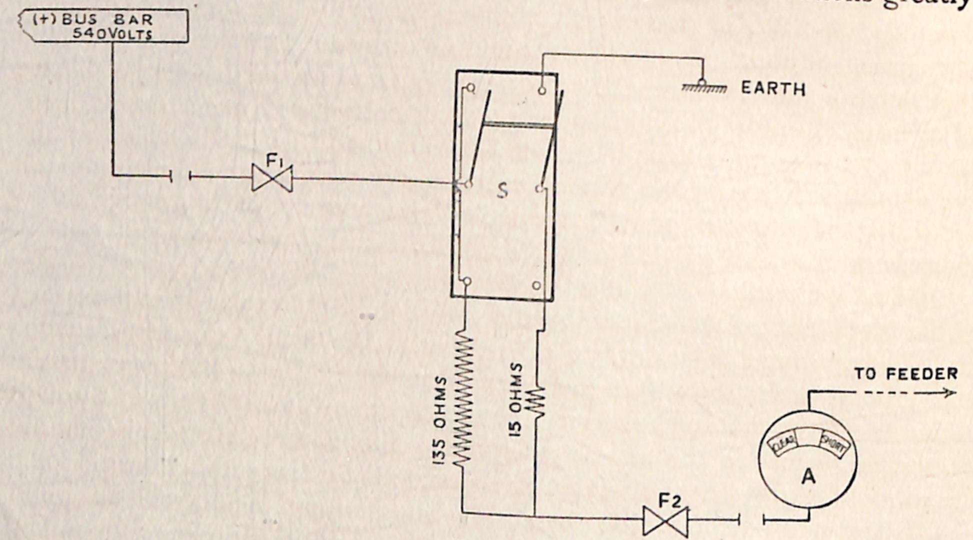


Fig. 90

When a feeder circuit-breaker opens it is a common practice to close it again; if it blows again, to close it after an interval of three seconds; but if it opens a third time, to leave it open; it being concluded that there is a permanent short somewhere. This rough-and-ready procedure is open to the objection of possibly causing damage to plant or to life from the shock of the voltage, and especially from the powerful arcs set up by the current from a cable whose circuit-breaker is probably set at well over 1000 amperes. To obviate this danger the Short Indicator designed by Mr. G. G. Braid of the Glasgow tramways is notably useful. The principle of the instrument will be understood from fig. 90.

A double-throw switch S has its middle point on one side connected through a fuse F_1 with the positive bus-bar, and its top and bottom contacts on the same side bridged together. On the other side the top contact is connected to earth; the bottom is a dummy and the middle point is connected to a resistance of 15 ohms, which has its other end joined to the end of a resistance of 135 ohms which is connected to the bottom contact of the left-hand side. The wire joining up the resistances is led through a fuse F_2 to an ammeter A which gives a full deflection for 4 amperes, but the scale of which is arranged to read "CLEAR" in the space which would normally read "0–2" amperes, and "SHORT" in that which would normally read "3–4" amperes. The other terminal of the ammeter is furnished with a lead for application to the feeder under test.

With the switch on the bottom contacts the voltage is plainly applied directly to the cable through the resistance of 135 ohms only. If there is a short, a current of 540 ÷ 135 = 4 amperes will pass, causing a full deflection, and thus indicating a short on A. With the switch on the top contacts the voltage passes the guard-resistance of 135 ohms and splits, part going through the ammeter and part to earth through the 15 ohms resistance. Now 15 ohms represents the cold resistance of the lamp circuits of 37 cars, supposing carbon lamps are fitted; hence if even such a large number of cars were on the feeder with their lamp circuits switched on, we should still have only 2 amperes passing through the ammeter, which would in consequence read "CLEAR". With a short, of course, sufficient current would shunt through the ammeter to indicate "SHORT".

Fault-locating.—For the location of faults on tramway mains the usual methods are, of course, available. First and foremost, for any success in locating a fault the length of the cable must be accurately known; without this the most skilful determination with the best instruments is utterly useless. The instruments used should be robust and of first-class quality, and as simple as may be. It would seem needless to say that the testing should be carefully done, did one not so constantly see this axiom neglected.

In tramway work trouble is at times experienced from the difficulty of obtaining anything in the way of a return for loop-testing. The trolley wire, if it can be thrown dead, may be used, or the core of a telephone or test cable. In any case, where the cable is looped to a conductor of different area the equivalent length of the loop must be calculated. This is a very easy matter. Suppose the length of the cable to be L feet, and its resistance per foot R ohms, and that it is looped to a conductor L_1 feet long with a resistance per foot of R_1 ohms, then clearly the total resistance of the loop will be $L R + L_1 R_1$ ohms, and its equivalent length in feet of the cable under test will be

$$\frac{L R + L_1 R_1}{R}, \text{ or } L + \frac{L_1 R_1}{R}.$$

For multicore cables nothing is better than a fall-of-potential test, the broken-down core being looped to a sound one. Then if D_1 is the deflection got between core 1 and earth, and D_2 that got between earth and 2, when a *steady* current flows round the loop, it is easy to show that the distance from the testing-station to the fault is

$$2 L \cdot \frac{D_2}{D_1 + D_2},$$

D_2 being the smaller deflection and L the length of the cable. The readings D_1 and D_2 must be averaged from readings got with the current flow reversed. Murray's loop is so well known that it scarcely requires any reference, beyond a caution that the contacts of the slide wire with the loop terminals must introduce no resistance, and that one must not be deluded into balancing to false zero. Any deflection on the galvanometer, noticed when it is joined up but the testing voltage not impressed, is merely due to some battery action at the fault. Another excellent null method is sketched in fig. 91. If, besides the broken-down cable, there are available two sound telephone or test cores, the latter should be joined up to the distant end in such a way as not to introduce any resistance at the joint δ. One of these is a voltmeter lead only, the other is a resistance (R_1), determined by measuring the resistance of the looped pair and dividing the result by two. To the near end of the cable (β) a uniform slide-wire is jointed in such a way as to introduce no resistance, and brought in contact with R_1 in such a way that no resistance is introduced. By sliding along the wire a position is found at which no deflection is got on the voltmeter V when a wire tapped through a bank of lamps on to the trolley wire or a live cable is applied to α. Then plainly the distance away of the fault is

$$L \cdot \frac{R_2}{R_1 + R_2}.$$

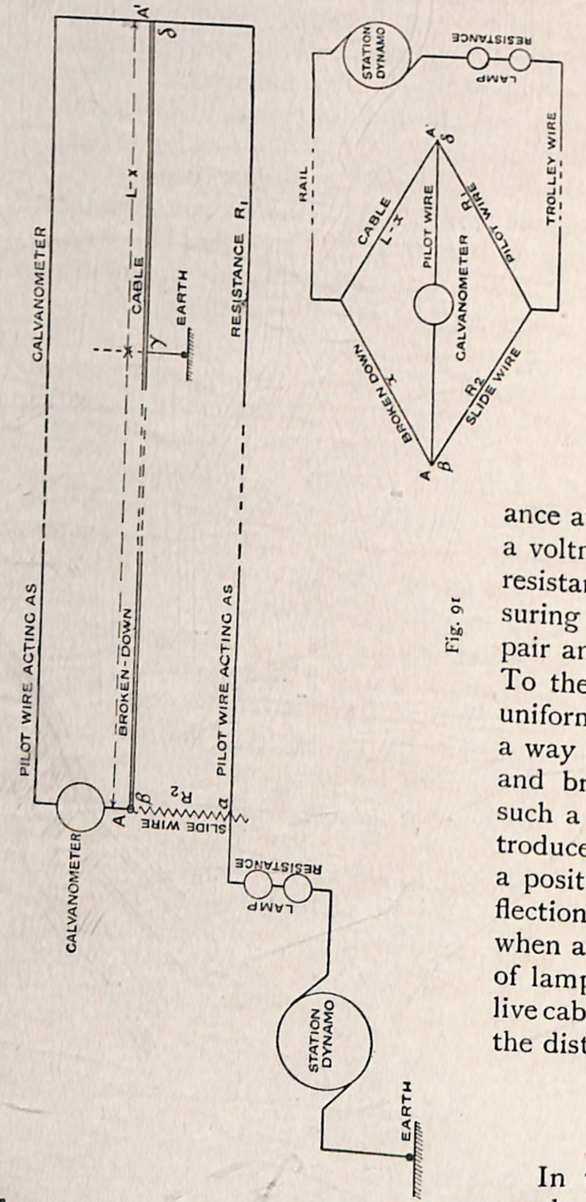


Fig. 91

In the case of a cable with its core broken in two, but well insulated from earth, it is possible to apply a capacity test, but it is not often that the chance is got. Generally the cable is well earthed. For a cable sheathed in vulcanized bitumen, without lead covering or armour, an induction test is sometimes successful. A frame in the shape of an equilateral triangle, with sides 1 yard long wound with 250 turns of No. 30 wire, and fitted with a very sensitive telephone receiver is suitable. The fault should be well broken down to earth, so as to admit of a current being sent through it amply large enough to entirely swamp the cable's capacity-current, and the current should be sent with a distinct set of slow rhythmical pulsations; such a signal as “ - - - —” being readily made out above the squealing sounds emitted by loaded cables. For lead-covered cables, especially laid solid, the test is a failure. When successful, the signals cease abruptly or become very much fainter when the fault is passed. Care must be taken to have the overhead work dead if one is going to tap the current through the fault from a section-box, else the surging of the current in the trolley wires will be heard in the telephone and prove utterly confusing. A better arrangement is shown in fig. 92. If a current of a few amperes be sent through the fault to earth, and a millivoltmeter with steel (not copper) contacts is applied along the *rail*, deflections will be obtained which on the faults being passed will abruptly change their direction and diminish greatly. This test can only be applied when there is nothing but the testing current flowing in the rails.

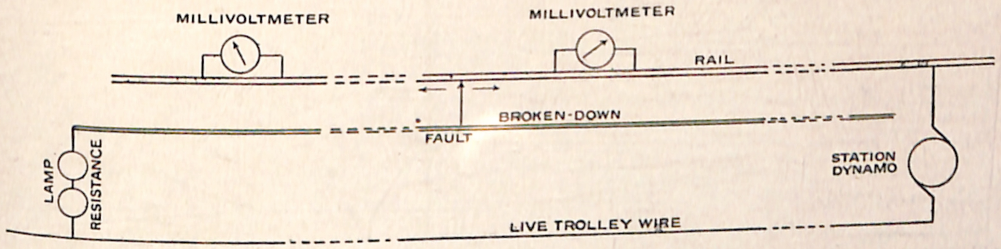


Fig. 92

For breaking down a cable, three transformers, coupled up with their low-tension windings in parallel and their high tension in series, will give thrice the voltage of one of them, which is usually ample. In the low-tension circuit a water resistance whose plates can be readily swung apart is a great advantage, as it enables the arc at the breakdown to be changed from its almost explosive character to a quiet discharge which soon welds up a satisfactory contact with earth.

Of course there is danger in such work, and all concerned should be familiarized with the procedure necessary in a case of electric shock. Notwithstanding its cost, the Pulmotor is so remarkably successful at resuscitation that one should be available in every electricity-supply concern.

CHAPTER VI

OVERHEAD CONSTRUCTION

General Considerations.—The overhead system may be divided into the following classifications:—

1. Span-wire construction (fig. 93), adaptable to practically all possible conditions of working.