TRAMWAY OVERHEAD WORK

MECHANICAL CONSIDERATIONS

SUSPENSION OF TROLLEY WIRES

RELATIVE POSITIONS OF WIRES AND TRACK

1. **Centre- and Side-Running Systems.**—In the system of tramways and railways known as the **overhead system**, the current is supplied to the car from a conductor suspended within reach of a collector carried by the car. If the conductor is suspended immediately above the centre of the track, the system is said to be **centre-running**; if the conductor is suspended at some distance from the centre of the track, the system is said to be **side-running**. The overhead conductor is usually known as the **trolley wire**. The centre-running system is the mechanically correct one, and side running is only adopted when it involves a cheaper and less unsightly construction, or when such mechanical difficulties are encountered as the presence of telegraph wires or road obstructions. The side-running system is also used at low bridges, where it is necessary to place the wires at one side, so as to give sufficient clearance for passengers on tops of cars. In side-running systems the distance of the trolley wire from the centre of the track should not exceed 8 feet, or there may be considerable trouble caused through collectors leaving the wires.

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TYPES OF OVERHEAD CONSTRUCTION

2. Span-Wire Construction.—One of the simplest and most satisfactory methods of suspending the trolley wire is to hang

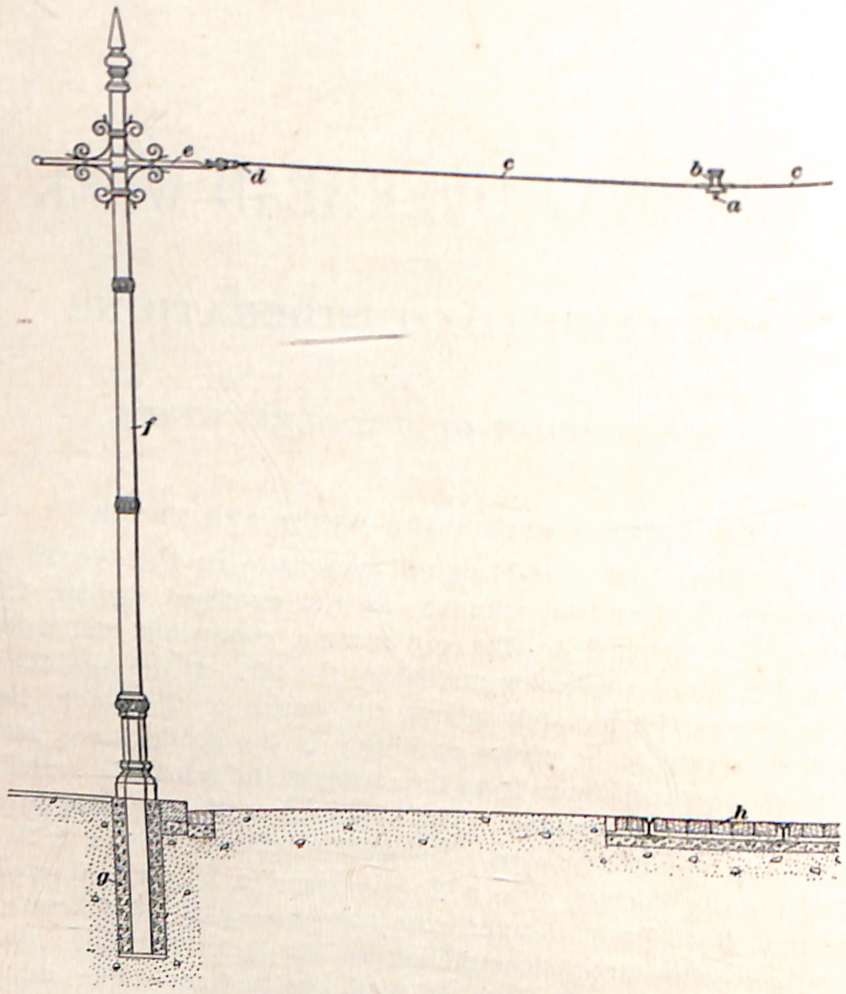


Fig. 1

it by means of insulators from a steel span wire stretched between poles on opposite sides of the track. This method is known as the **span-wire construction,** and is very extensively used both in Great Britain and abroad. This type of construction is shown in Fig. 1, which illustrates the arrangement for

centre-running on a double track. The construction is only shown for one half of the street, the other half being exactly similar. The trolley wires *a* are supported by the insulated hangers *b*, which are attached to the steel span wire *c*. Where trolley wires are suspended from span wires, the Board of Trade requires that there shall be double insulation between the trolley wire and earth. On this account the span wire *c* is terminated at each end in the insulators *d*, which are so constructed that the tension on the span wire can be adjusted. The insulators *d* are attached to brackets *e* fixed to the posts *f*, which are embedded in concrete *g*. Each trolley wire is vertically above the centre of its track *h*. The Board of Trade regulations provide that the height of the trolley wire above the surface of the roadway must not be less than 20 feet, except where the line passes under low bridges.

3. Advantages of Span-Wire Construction.—The span-wire construction has many advantages, the chief of which are that it does not obstruct the centre of the roadway, and it gives a very flexible support to the trolley wire. Also, where a single track is laid, with the prospect of making it a double track if the traffic warrants doing so, the span-wire construction leaves very little additional work to be done when the time comes for doubling the track. In such a case, it is sometimes the practice to erect two trolley wires side by side, about 8 or 10 inches apart. As long as the road is single track, the cars use one wire when going one way and the other wire when returning; this saves overhead special work at turnouts and saves copper in the feeder cables. When the time comes for doubling the track, it is only necessary to slide one wire into place over the new track.

In Fig. 2, *a b* is one trolley wire and *c d* is the other; *T* is a turnout where cars can pass each other. The dotted line *e f* shows the position of the wire *a b* after it has been moved over to the second track. In Fig. 1 the poles are placed in the kerb line, but in some cases they are placed at the back of the path

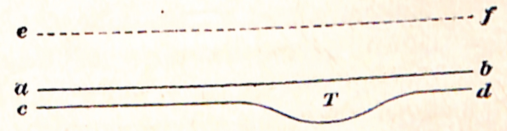


Fig. 2

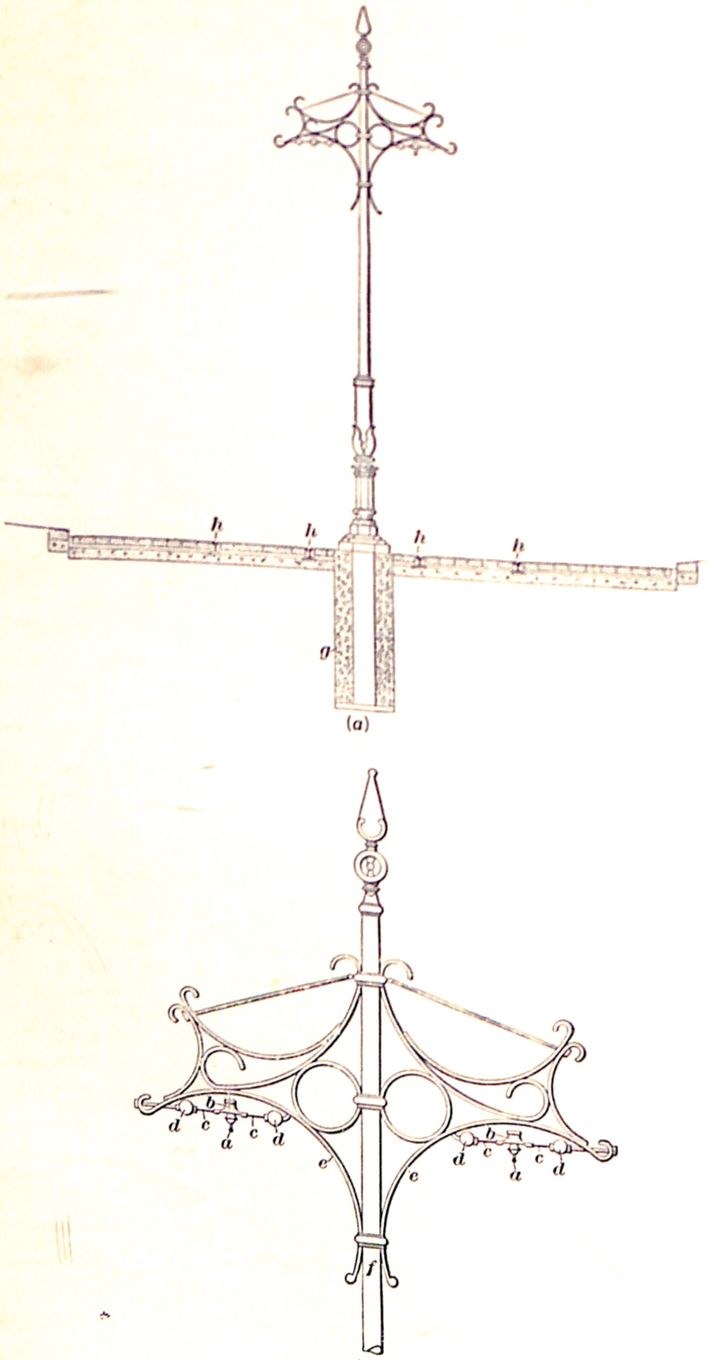


FIG. 3

to avoid obstructions or to suit the wishes of the district surveyor.

4. Centre-Pole Construction.—In very wide roads, where the presence of poles in the centre of the road is not objectionable, the centre-pole construction is often adopted. This method of

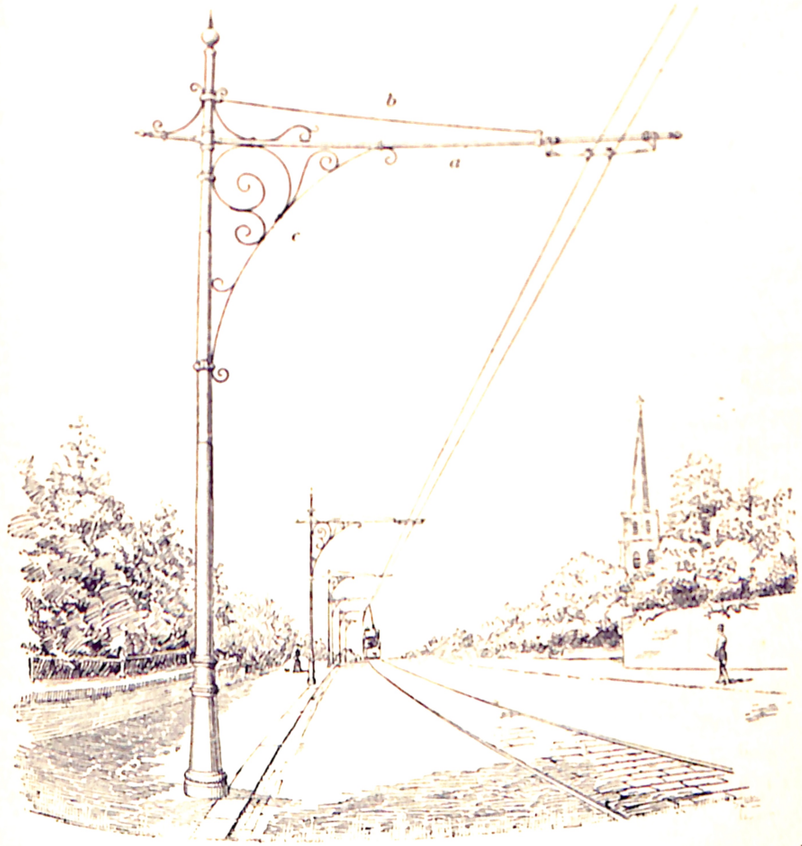


FIG. 4

suspending the trolley wires for side-running on a double track is shown in Fig. 3 (*a*); in view (*b*) is shown the top of the pole drawn to a larger scale. The trolley wires *a*, view (*b*), are supported by the insulated hangers *b*, which are carried by short lengths of steel wire *c* fixed to *strain insulators d*. These strain insulators are attached to the brackets *e*, which are clamped to

the pole *f*. The poles are set in concrete *g*, as before. The trolley wires are suspended almost directly above the inside lines of rails of the track *h*. This type of construction is cheaper than the span wire, as it enables the two trolley wires necessary for a double track to be carried by a single line of poles.

5. Side-Bracket Construction.—Where the trolley wires can be supported, not more than 8 feet from the centre of the track, by an arm not exceeding 16 feet in length, the **side-bracket construction** is often used. In some cases arms over 20 feet long have been used, but such arms are mechanically weak, and should only be adopted where the span-wire system is not permissible. The side-bracket construction is shown in Fig. 4, where the arrangement of insulators, etc., is the same as for the other types of construction. Part of the weight on the bracket arm *a* is taken by the tie-rod *b*, and the bracket is further strengthened by the ornamental scrollwork *c*. In both the centre-pole and side-bracket types of construction, the insulators supporting the trolley wire are usually carried by short lengths of span wire. This enables the necessary double insulation to be provided between the trolley wire and earth, and also provides an elastic support for the trolley wire, to absorb the blow given by the collector when passing the point of support of the trolley wire. The life of the trolley wire and support is thus much increased.

POLES AND ROSETTES

6. Types of Poles.—The poles used for tramway work in Great Britain are of mild steel, although wooden poles are used in America and on the Continent. The steel poles are commonly *tubular poles*, though *lattice poles* are occasionally used; the latter, however, find a larger application in railway work.

7. Tubular Poles.—**Tubular poles** are generally made in three sections, each of which is a solid-drawn tube, or a tube made by rolling a steel plate into tubular form and lap welding the edges. When the poles are made of lap-welded tube, the welds in the three sections are placed at 120° to one another. The sections of the poles are welded together under pressure.

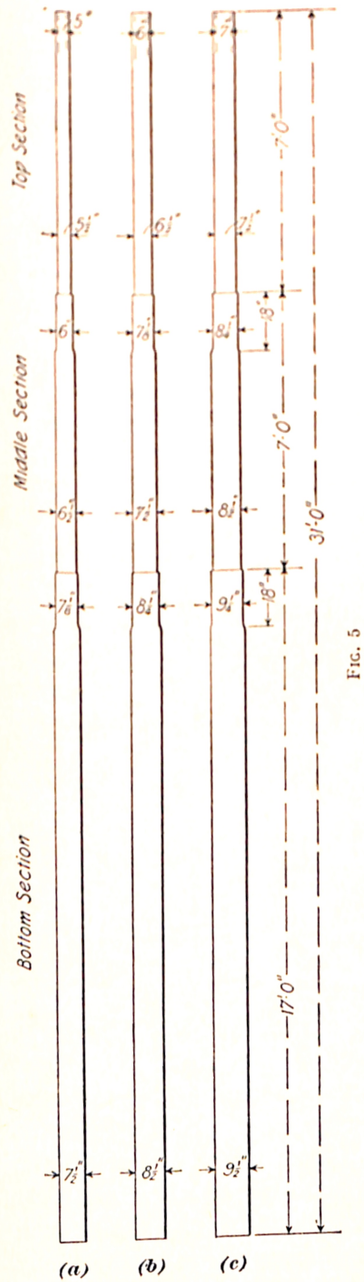


FIG. 5

Tubular poles are also made from one length of steel plate, turned over and butt-welded along its whole length. When this method of construction is adopted, the poles are tapered, and are called taper poles.

8. Sectional poles are made in three standard sizes, *light*, *medium*, and *heavy*. They are 31 feet long and the joints between the sections are 18 inches long. Their dimensions are shown in Fig. 5, where (*a*) is a light pole, (*b*) a medium pole, and (*c*) a heavy pole. Each pole is usually fitted with ornamental cast-iron collars at the joints, a cast-iron base, and a cast-iron top, known as a *finial*. The connection of the span wires to the poles is made either to a light steel strap clamped round the pole or to a short bracket clamped to the pole and fitted with ornamental scrollwork. The light poles may be used on straight runs for bracket work and for span work where the span is not too great. Medium poles should be used for brackets having arms from 7 to 16 feet long, for wide spans, and on curves. Heavy poles should be used for terminal and anchor poles, and where there are complicated junctions.

9. Tests for Standard Poles.—Standard tramway poles are usually required to conform to the following tests, a certain percentage of each batch being selected for testing purposes: (*a*) The pole shall be dropped vertically, butt downwards, three times in succession, from a height of 6 feet, on to a hard wooden block 6 inches thick laid on a concrete foundation, and shall not show any signs of telescoping or loosening of joints. (*b*) The pole shall in each case be rigidly supported for 6 feet from the butt, and loaded, as a cantilever, 18 inches from the top, the load being applied at right angles to the axis of the pole, which shall be fixed horizontally. On the application of the loads given in Table I, the temporary deflection and permanent set, measured at the point of application of the load, shall not exceed 6 inches and $\frac{1}{2}$ inch, respectively. The standard taper poles are not subjected to the first test, because they are made in one piece, but both sectional and taper poles must pass the second test.

TABLE I

STANDARD TESTS FOR STEEL TRAMWAY POLES

Class of Pole	Load for Temporary Deflection not Exceeding 6 Inches Pounds	Load for Permanent Set not Exceeding $\frac{1}{2}$ Inch Pounds
Light	750	1,000
Medium	1,250	1,750
Heavy	2,000	2,500

10. Lattice Poles.—Lattice poles are very largely used on the Continent for work in suburban and country districts, and have been recently used for tramway work in Great Britain. The method of constructing them is shown in Fig. 6. The type shown in view (*a*) consists of two steel channels *a*, braced together by steel strips *b*; that shown in view (*b*) consists of four steel angles *c* arranged in a square, and tied together on all four sides by the steel strips *d*. For tramway work, the poles formed in either of these ways are tapered off along their length, being large at the base and small at the top. For railway work, the sides are usually parallel throughout their length.

11. Erection of Poles.—Tramway poles are usually set 6 feet in the ground and surrounded by concrete. The thickness of concrete required depends on the nature of the soil, the looser the soil, the thicker being the layer of concrete necessary; the usual thickness for ordinary construction is about 9 inches. A slab of concrete or stone should be placed at the bottom of the hole for the pole to stand on; this will tend to prevent sinking. When excavating holes for the poles, the surrounding

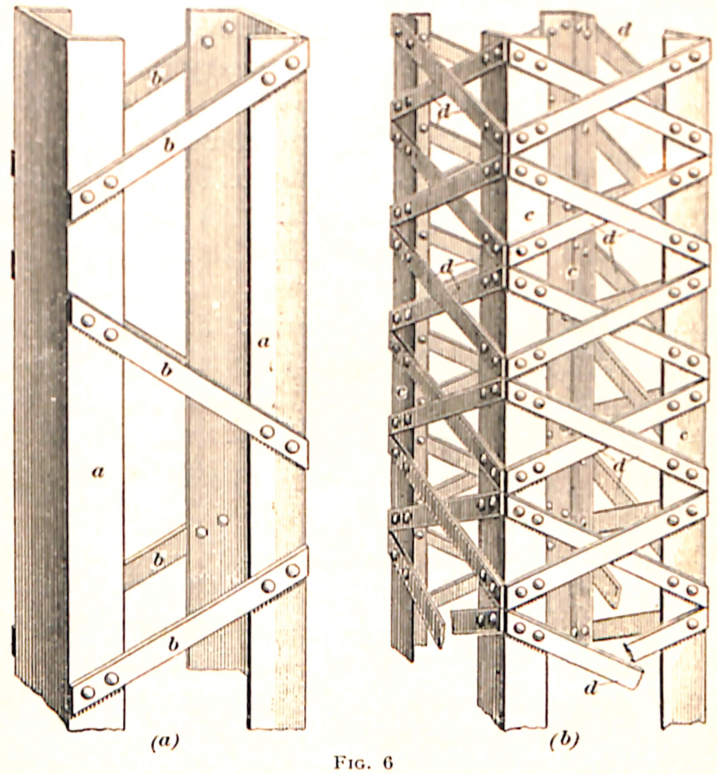


FIG. 6

soil should not be disturbed more than is absolutely necessary, and only concrete should be used for filling the hole. When erected, the poles are given such a rake that when the trolley wire is strung in position the poles will be as nearly vertical as possible. The amount of this rake depends on the strength of the pole, the weight of the overhead fittings, the nature of the soil, the width of street in the case of span wires, and the length of the bracket for side-bracket construction. It varies from

about 3 inches for light straight-line work to 12 inches for heavy curves and terminal posts. Centre poles for straight-line work should be erected vertically, for the bending effect due to the wire on one side counteracts that on the other. The maximum distance apart between the poles in the direction of the track is limited by the Board of Trade to 120 feet. After erection, the poles should be allowed to set for from 5 to 7 days before the trolley wire is erected.

12. Rosettes.—In cases where there are substantial buildings along the tramway route, and the necessary permission can be obtained, the poles may be dispensed with, and attachments made to the buildings by means of rosettes, the span-wire construction being used. A common type of rosette is shown in Fig. 7. It consists of an ornamental casting *a* that is attached to the building by means of four special bolts. The insulator or span wire is then attached to the eye-bolt *b*, which is screwed into a circular casting *c*. This circular casting has a hole through its centre which is bushed with rubber, and it is attached to the lugs on the main casting *a* by means of the bolt *d*, which passes through the bush. This rubber bush prevents the vibration of the trolley wire being transmitted to the buildings; large rubber washers *e* further help to deaden the vibration. The use of rosettes cheapens the cost of the overhead construction to a very great extent, but they can seldom be used for any considerable distance.

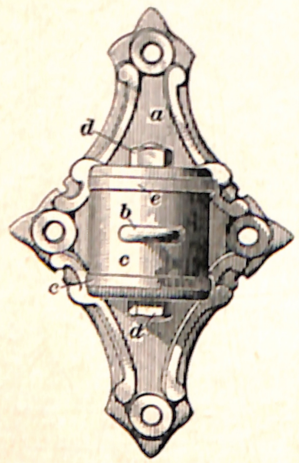


FIG. 7

SPAN AND GUARD WIRES

13. Span Wires.—Span wires for supporting the trolley wires nearly always consist of stranded galvanized-steel wires. The number of strands used in British practice is in most cases uneven. For ordinary straight construction, a span wire

consisting of 7 strands of No. 12 S.W.G. is often used. The sizes and breaking loads of various sizes of span wire are given in Table II.

TABLE II

STRANDED GALVANIZED-STEEL WIRES

Gauge of Each Strand S.W.G.	Diameter of Each Strand Inch	Number of Strands	Approximate Diameter of Stranded Wire Inch	Approximate Breaking Load Pounds	Approximate Weight Per 100 Feet Pounds
8	·160	7	$\frac{1}{2}$	8,320	52·00
9	·144	7	$\frac{7}{16}$	6,050	42·50
10	·128	7	$\frac{3}{8}$	4,550	28·75
12	·104	7	$\frac{5}{16}$	3,950	18·62
14	·080	7	$\frac{1}{4}$	2,400	12·12
17	·056	7	$\frac{3}{16}$	1,600	8·75

14. Guard Wires.—Where telegraph or telephone wires, unprotected by an insulated covering, are liable to fall or be blown on to the trolley wires, the Board of Trade enacts that guard wires shall be provided over trolley wires. These guard wires must be efficiently earthed. The smallest size permitted is 7 strands of No. 16 S.W.G., or a single strand of No. 8 S.W.G. The earth connection should be made by connecting the guard wire through the support to the rails by means of a copper bond. The guard wires are generally carried by the same poles as the trolley wires. The various arrangements of guard wires are shown in Fig. 8 (*a*) to (*e*), in which the trolley wires are lettered *a* and the guard wires *b*.

15. Where telephone wires weighing less than 100 pounds per mile cross the trolley line, the Board of Trade regulations are as follows:

(*a*) Where there is one trolley wire, two guard wires should be erected, as shown in Fig. 8 (*a*). (*b*) Where there are two trolley wires at a distance not exceeding 12 feet apart, two guard wires should be erected, as shown in view (*b*). (*c*) In special cases, at junctions or curves, where parallel guard wiring would be complicated, two guard wires only will generally suffice if so erected that a falling wire must fall on them before it can fall on the trolley wire.

When the wires which cross the overhead work weigh over 100 pounds per mile, the regulations are as follows:

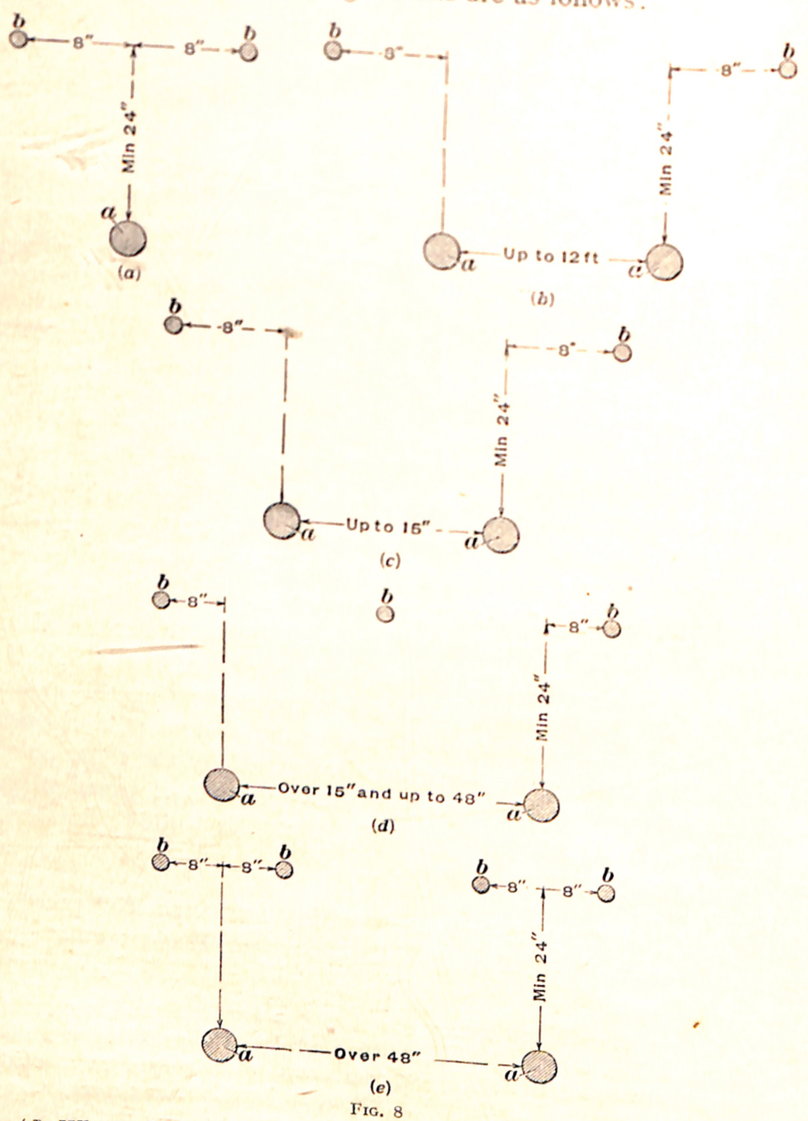


FIG. 8

(*d*) Where there is only one trolley wire, two guard wires should be erected, as shown in view (*a*). (*e*) Where there are two trolley wires not more than 15 inches apart, two guard wires should be erected, as shown in view (*c*). (*f*) Where there are two trolley wires and the distance between them exceeds 15 inches, but does not exceed 48 inches, three guard wires should be erected, as shown in view (*d*). (*g*) Where the distance between the two trolley wires exceeds 48 inches, each trolley wire should be separately guarded, as shown in view (*e*).

16. Where telegraph or telephone wires run parallel to a trolley wire, or are liable to fall on, or to be blown on to, a trolley wire, a guard wire should be so erected that a falling wire must fall on the guard wire before it can fall on the trolley wire. If the trolley wire is enclosed within a triangle formed by the vertical plane of a telegraph wire and an imaginary line drawn at an angle of 45° from the uppermost telegraph wire on the side nearest to the trolley wire, a guard wire should be erected on span wires or on the brackets. This indicates the minimum requirements. In very exposed situations, or for heavy routes of wires, more than one guard wire may be needed. When guard wires are attached to other supports than the poles carrying the trolley wires, they should be connected with the rails at one point at least. When it is possible that a telegraph wire may fall on an arm or a stay, or a span wire, and so slide down on to a trolley wire, guard hooks should be provided.

17. If the guard wires are so arranged that the fallen wire cannot make contact with a trolley wire without also touching a guard wire, the trolley wire will be earthed, and the circuit-breaker at the power station will open. Small fuses or heat coils are placed in the circuits of all telegraph and telephone instruments, so that, in the event of a connection with any tramway or electric-light wires, the fuses will blow and protect the instruments. Many engineers are opposed to the use of guard wires, but there is no doubt that the best procedure is to avoid overhead crossings altogether, and to run all telegraph and telephone cables underground, either altogether, or at least at crossing points. The resistance to earth of all guard wires should be periodically tested, in order to see that the earth connections are in good condition. For the guard wires to be really effective, their connections to the track rails should be solidly made, and be of negligible resistance.

TROLLEY WIRE AND FITTINGS

TROLLEY WIRE

18. Copper Trolley Wire.—The trolley wire used for all ordinary work is of hard-drawn high-conductivity copper. It is seldom less than No. 0 S.W.G., while No. 00 is the size most frequently used. Some of the roads recently built use No. 000 or No. 0000, as it gives a stronger construction in addition to reducing the voltage drop. If the feeding system is laid out

TABLE III

HARD-DRAWN COPPER TROLLEY WIRE

Gauge	Diameter Inch	Sectional Area Square Inch	Weight Per 1,000 Yds. Pounds	Weight Per Mile Pounds	Breaking Stress Pounds
0000000 S.W.G.	·500	·1964	2,276	4,005	9,150
000000 S.W.G. .	·464	·1691	1,955	3,441	8,330
0000 B. & S. .	·460	·1661	1,921	3,381	8,370
00000 S.W.G. .	·432	·1466	1,695	2,983	7,390
000 B. & S. . .	·410	·1320	1,527	2,687	6,790
0000 S.W.G. .	·400	·1257	1,453	2,557	6,450
000 S.W.G. . .	·372	·1087	1,256	2,212	5,600
00 B. & S. . .	·365	·1046	1,209	2,129	5,390
00 S.W.G. . .	·348	·0951	1,100	1,935	4,900
0 B. & S. . .	·325	·0829	958	1,692	4,270
0 S.W.G. . .	·324	·0824	953	1,678	4,250

properly, larger wires are quite unnecessary. Hard-drawn copper is used because its tensile strength is greater and its wearing qualities better than soft copper. Its resistance is slightly higher, but this is of little consequence because the trolley wire is not usually depended on to carry the current for any great distance. Table III gives particulars of size, weight, and tensile strength

for some of the standard sizes of hard-drawn copper. The variation in diameter should in no case exceed ·0005 inch.

19. Special Trolley Wire.—For curves and other places where the wear and strain on the trolley wire are greater than usual, special composition trolley wire is sometimes used. One of the best compositions is silicium bronze, the breaking stress of which is

TABLE IV

SILICIUM-BRONZE TROLLEY WIRE

Gauge	Diameter Inch	Sectional Area Square Inch	Weight Per 1,000 Yds. Pounds	Weight Per Mile Pounds	Breaking Stress Pounds
0000000 S.W.G.	·500	·1964	2,276	4,005	13,940
000000 S.W.G. .	·464	·1691	1,955	3,441	12,130
00000 S.W.G. .	·432	·1466	1,695	2,983	10,670
000 B. & S. . .	·410	·1320	1,527	2,687	9,740
0000 S.W.G. .	·400	·1257	1,452	2,557	9,390
000 S.W.G. . .	·372	·1087	1,257	2,212	8,150
00 B. & S. . .	·365	·1046	1,209	2,129	7,960
00 S.W.G. . .	·348	·0951	1,099	1,935	7,240
0 S.W.G. . .	·324	·0824	953	1,678	6,370

about one-third greater than that of hard-drawn copper. Its wearing properties are much greater, and its conductivity is about 70 per cent. The weights, sizes, and breaking stresses for some of the gauges in which it is made are given in Table IV.

EARS

20. Soldered Ears.—In order to support the trolley wire in position, gunmetal fittings, called **ears,** are attached to it at the span wires or bracket arms. A common form of ear is shown in Fig. 9, (*a*) being a plan, and (*b*) a side view; views (*c*) and (*d*) show sections on the lines *A B* and *C D*, respectively. The groove *a* in the ear is placed over the trolley wire, and the sides of the

groove are hammered in. Flux is then applied and the trolley wire is firmly soldered to the ear, after which all superfluous solder is removed and the ear and trolley wire made perfectly

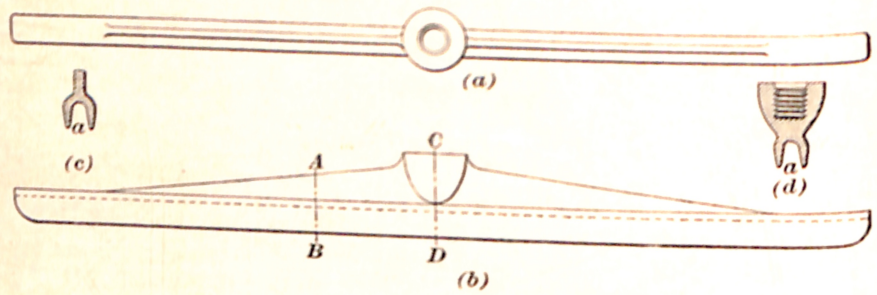


FIG. 9

smooth, as shown in Fig. 10, where *a* is the ear and *b* the trolley wire. In Great Britain, current is usually collected from the trolley wire by a grooved wheel, called a **trolley wheel.** On this account, the ear should not increase the diameter of the trolley wire very much, as hammering and sparking will result, and the life of the trolley wire will be determined by its life at the ears. Ears of this type should be carefully tapered off at the ends, so that the collecting wheel may pass under them without a jolt.

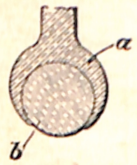


FIG. 10

21. Mechanical Ears.—To get over the trouble caused by the jolting of the trolley wheel as it passes ears, trolley wires with grooved and figure-8 sections have been tried, in conjunction with mechanical ears screwed on to the wire, and so designed that the trolley wheel does not strike them in passing. The way in which the figure-8 section is held is shown in Fig. 11 (*a*), *a* being the ear between the jaws of which the trolley wire *b* is clamped by means of screws. Fig. 11 (*b*) shows the arrangement for a grooved-section trolley wire, the jaws *a* of the ear fitting into the grooves *b* in the trolley wire.

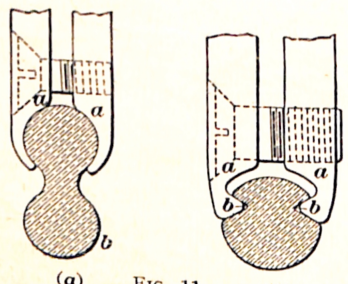


FIG. 11

22. A common type of mechanical ear for use with grooved wire is shown in Fig. 12, where *a* is the socket into which the supporting bolt is screwed, *b* the movable clamping jaw, *c* the clamping screws, and *d* the grooved wire. In erecting curve ears, care must be taken to keep the main casting on the inside of the curve, for if the clamps are placed on the inside the whole strain of the curve will come on the screw heads, which are liable to be sheared off. The special sections of trolley wire used with mechanical ears are not, however, very satisfactory. The figure-8 wire, when used in long spans, has a tendency to lie over on one side and throw the trolley wheel off the wire. Where a grooved wire is used for side-running, the wire wears away very quickly, the extreme edge of the section being gradually rolled into the groove, which soon disappears. For these reasons circular wires with soldered ears are by far the best, and are much more generally used than

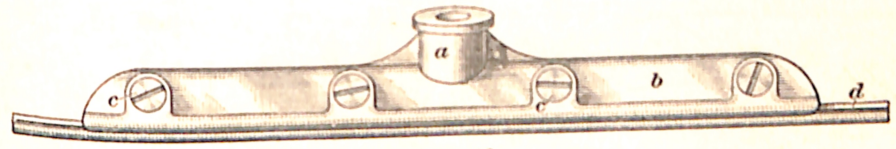


FIG. 12

special sections with mechanical ears. Ears for use on straight lines are commonly made 15 inches in length, but experience shows that a length of 24 inches gives much better results, and for curves, a length of 36 inches is more suitable.

23. Special Ears.—Some special types of ears, intended for soldering to the trolley wire, are shown in Fig. 13. The ear shown in (*a*) is known as a **strain,** or **anchor, ear,** and is so called because it is provided with eyes *a* to which anchor wires can be attached. In (*b*) is shown a **half-anchor ear,** which is only provided with one eye *a*. These types of anchor ears are soldered to the trolley wire at the points where breakages are most likely to occur, and the eyes are attached by means of short lengths of span wire to insulators fixed to the fittings. When the trolley wire breaks, it remains suspended from the anchor, and no long delay is caused to the cars, though the trolley must be lowered and the cars pushed past the faulty point. Fig. 13 (*c*) shows

a **feeder ear**, which is provided with a special connection *b* to which the feeder is attached. In Fig. 13 (*d*) is shown a splicing

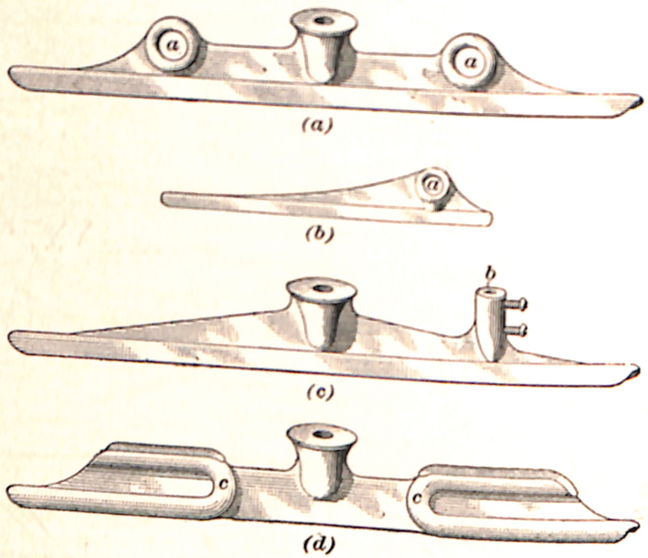


FIG. 13

ear, which is used where it is necessary to make a joint in the trolley wire at a hanger. The ends of the wire are passed up through the ear and bent over into the grooves *c*.

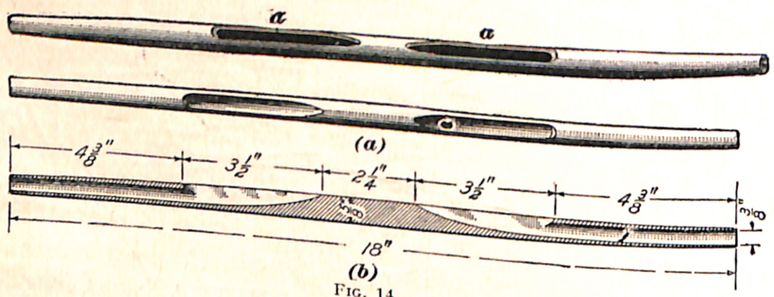


FIG. 14

24. When it is necessary to make a joint in the wire between hangers, a tinned tapering gunmetal sleeve, known as a **splicing sleeve**, is used. This device is shown in Fig. 14 (*a*) and (*b*); the ends of the trolley wires go in at each end of the sleeve and

are bent up through the openings *a*, *a*. The remaining space is then poured full of melted solder and the ends of the wire trimmed off. This connector will give excellent service if care is taken to see that it is made of heavy enough material and is a good fit for the wire. In view (*b*) are shown the dimensions for a satisfactory connector for No. 00 B. & S. wire. Splicing ears and splicing sleeves are very rarely used, owing to the fact that trolley wire is supplied in ½-mile lengths, and at the end of each ½ mile a special fitting, called a *section insulator*, must be used.

INSULATING FITTINGS

25. Types of Insulating Fittings.—The **insulating fittings** used in overhead construction may be divided into three broad classes, according to the purposes for which they are used: (*a*) The fittings used to insulate the trolley wire from its supporting span wire or bracket, the chief of which are *straight-line hangers*, *double pull-offs*, and *single pull-offs*. (*b*) The fittings used to insulate the span wire from the poles or supports, known as *Brooklyn insulators*, *globe* or *strain insulators*, *insulated turnbuckles*, and *reel insulators*. (*c*) The fittings used to insulate two sections of trolley wire from each other, called *section insulators*.

26. Straight-Line Hangers.—The hangers for suspending the trolley wire in straight-line construction are made in a variety of designs, but in general they consist of a casting, or body, which is held by the span wire or bracket, and a bolt, cased in insulating material, from which the ear holding the trolley wire is suspended. A common form is shown in Fig. 15, where *a* is the main casting, which is provided with two grooved arms *b*. The span wire passes through the grooved arms *b* and presses into the groove on the main casting, as shown at *c*, thus holding the hanger in position. By using a special tool, hangers can be easily sprung into position on the span wire after it is

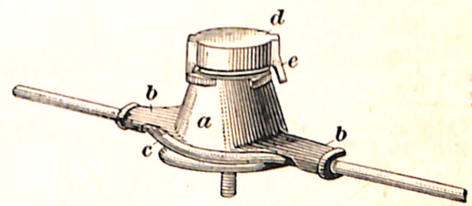


FIG. 15

erected. The top of the hanger is covered by a screw-cap *d*, which is prevented from unscrewing by bending down the lugs *e* so that they engage with small projections from the casting *a*.

27. The construction of the straight-line hanger is shown in Fig. 16, (*a*) being a plan, (*b*) an elevation, and (*c*) a section on the line *A B*, view (*b*). The main body of the casting is shown at *a* and the grooved arms at *b* ; *c* is the bolt round which is moulded the insulation *d*. The lower end *e* of the bolt is threaded so that it can be screwed into the ear to which the trolley wire is attached. Just above the screw thread the bolt is provided

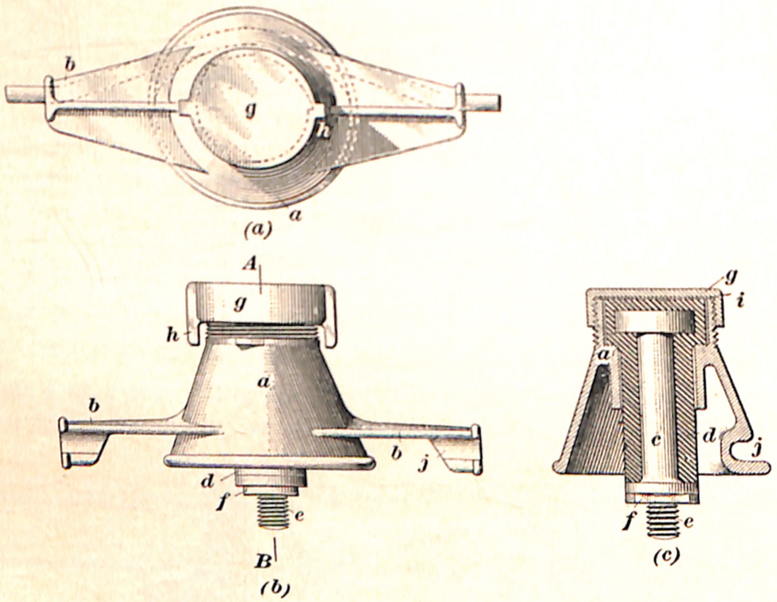


FIG. 16

with flat sides *f* to permit of its being gripped by a wrench and screwed into the ear. The whole of the insulated bolt is free to turn in the main body *a* of the casting ; it is kept in place by the screw-cap *g*, the lugs which keep the cap from unscrewing being shown at *h*. The cap is prevented from damaging the insulation of the bolt, owing to being screwed on too tightly, by the leather washer *i*. The span wire rests in a groove *j* in the main casting. The advantages of this type of hanger are

that the insulation is completely protected from damage due to blows from the trolley arms of cars, that the insulating bolt can easily be replaced by removing cap *g* and unscrewing the bolt from the ear, and that even if the insulation of the bolt is entirely destroyed the trolley wire cannot fall, because the head of the bolt is too large to pass through the hole in the main casting.

28. The main castings of straight-line hangers are made both in galvanized malleable iron and in gunmetal. The iron hangers are the cheaper, but the gunmetal hangers are the more durable, as they resist corrosion much better. Straight-line hangers are sometimes required for direct attachment to a bracket arm without the use of a span wire ; the type used for this purpose is shown in Fig. 17. Double insulation between the trolley wire and the pole is obtained by the use of the insulating tube *a*, which fits over the bracket arm. The tube is surrounded by the split sleeve *b*, which is clamped up by the bolts *c*. A certain amount of flexibility is obtained, as the main body of the hanger *d* is able to pivot round the bolt *e* which attaches it to the split sleeve.

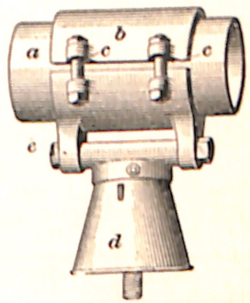


FIG. 17

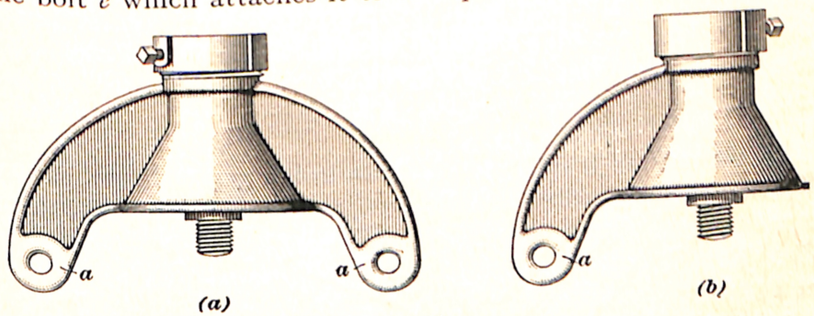


FIG. 18

29. Double and Single Pull-Offs.—At curves, where the trolley wire is subjected to considerable side strain, the straight-line hanger is not satisfactory, as it tilts over. Therefore special hangers, known as **double** and **single pull-offs**, must be used. These are so designed that the direction of the side pull due to

the trolley wire passes through the point of attachment to the span wire. When used on a span wire, these fittings support the weight of the line, but they are often used in positions where they only take side strains. The double pull-off shown in Fig. 18 (*a*) is provided with two arms *a* for attachment to the span wire; the single pull-off, view (*b*), has only one arm *a*. The internal construction of these pull-offs is identical with that of the straight-line hangers.

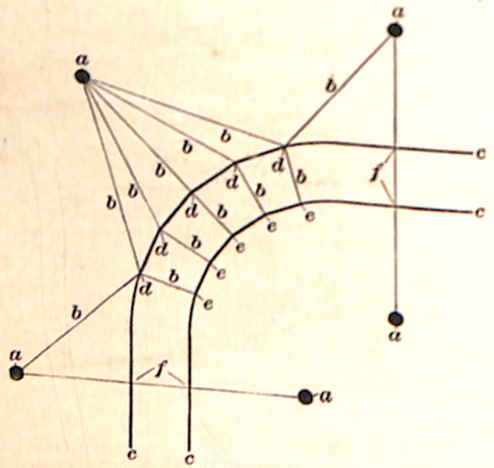


FIG. 19

30. Method of Using Pull-Offs.—The way in which pull-offs are used in curve work is shown in Fig. 19. The poles are shown at *a*, the pull-off wires at *b*, and the trolley wires at *c*. Double pull-offs *d* are used next to the poles, and single pull-offs *e* on the inside curve. Straight-line hangers are used at the points *f*. The arm of the double pull-off next the pole has to stand the side pull of both trolley wires, while the arm away from the pole has only to stand the pull of one trolley wire.

31. Brooklyn Insulator.—A strain insulator much used for insulating the span wire from the pole, and known as the **Brooklyn insulator,** is shown in Fig. 20. It consists of an insulated bolt *a* similar to that used in straight-line hangers, but tapped out at the end to take an eye-screw *b*, by means of which the tension on the span wire can be adjusted. The head of the insulated bolt is held in the

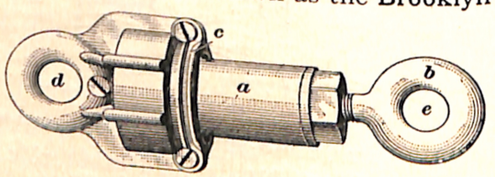


FIG. 20

casting *c*, which is attached to the pole bracket by a bolt which passes through the eye *d*. The span wire is attached to the other eye *e*. One of these insulators will take up a slack of 3 inches. The standard-size insulator weighs 2 pounds 10 ounces, and the extra-heavy size, 5 pounds 12 ounces.

32. Globe, or Strain, Insulators.—Globe, or strain, insulators, such as those shown in Figs. 21 and 22, are sometimes used instead of Brooklyn insulators on account of their cheapness. On some systems, it is the practice to use globes at one end of the span and Brooklyns at the other. A form of globe insulator which finds a large application consists of two metal eyes *a*, *b*, Fig. 21, that have enlarged ends *c*, *d*. These ends are surrounded by a metal ring *e*, and the whole is insulated by being cast into the ball of hard insulating material *f*. Another type of strain insulator is shown in Fig. 22, (*a*) being the exterior appearance of the insulator and (*b*) a section. The two castings *a* are insulated from each other and from a third casting *b*, which takes the strain. Both of these types are so constructed that, even if the insulating material were to be entirely destroyed, the wires would not fall, because the metal parts are interlocked. Table V, which gives the breaking load and the breakdown voltage of strain insulators of the Brooklyn and

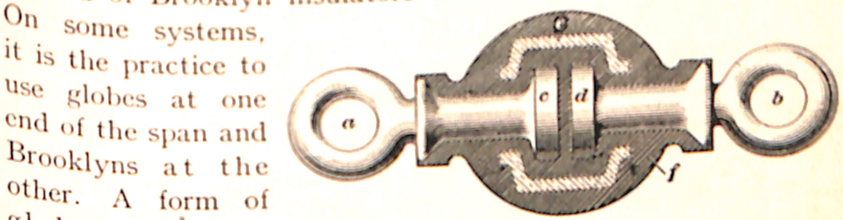


FIG. 21

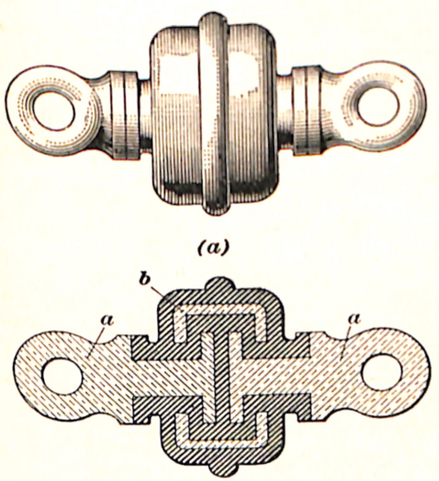


FIG. 22

globe types, shows that they are strong both mechanically and electrically.

33. Insulated Turnbuckle.—The construction of an insulated turnbuckle is shown in Fig. 23, (*a*) being a plan and (*b*) a sectional elevation. The turnbuckle consists of a link *a* into the opposite ends of which screw two threaded rods *b*, *c*. One rod *b* is furnished with a right-hand thread and the other rod *c* with a left-hand thread; therefore, turning the link *a* in one direction draws the rods together, and turning it in the other direction screws them apart. One rod *c* terminates in an ordinary eye *d*, but the eye *e* attached to the other rod *b* is embedded in insulation *f*. The hole in the insulation at the centre of the eye is furnished with a brass bush *g* to protect the insulation from damage. An insulated turnbuckle is capable of taking up a slack of 6 inches.

TABLE V

BREAKING LOAD AND BREAKDOWN VOLTAGE OF STRAIN INSULATORS

Type of Insulator	Breaking Stress Pounds	Breakdown Voltage
Brooklyn, small . . .	9,000	10,000
Brooklyn, large . . .	18,000	10,000
Globe 2½-inch diameter	6,000	7,000
Globe 3-inch diameter	9,000	10,000

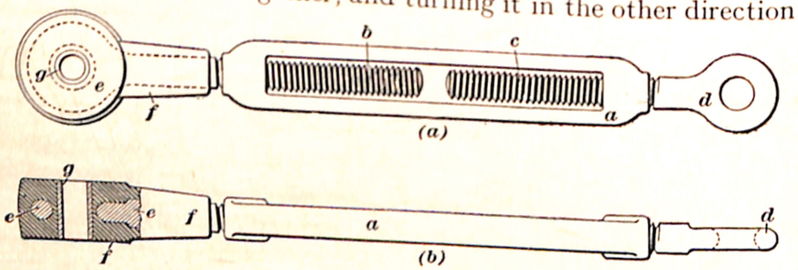


FIG. 23

34. Reel Insulator.—A type of insulator which is coming into favour for insulating the span wire from the pole is the simple brownware reel shown in Fig. 24. A bolt passing through the centre hole *a* secures the reel to the bracket arm, and the span wire is fastened round the groove *b*. These insulators are very cheap and their insulating properties do not deteriorate.

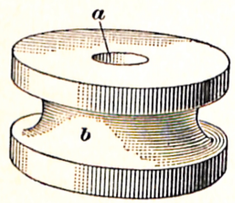


FIG. 24

35. Section Insulators.—Section insulators are used to divide the overhead line into ½-mile sections insulated from one another, as required by the Board of Trade. A common design is shown in Fig. 25 (*a*). The trolley wires are attached to the end castings *a* in the same manner as to a splicing ear. These end castings are connected in three places by insulating pieces *b*, *c*, *d*. The part *b* is made up of two insulated bolts of the same type as those used in straight-line hangers. These bolts are screwed into the end castings and the heads are connected by a coupling *e*. The insulating part *c* is a compression strip of hardwood, and resists the tendency of the strain on the trolley wire to pull the castings together at the top. The coupling *e* has two extensions *f* cast on to it for the attachment of the span wires. The two castings *a* are joined by the strip of hardwood *d*, so that an unbroken and smooth surface is provided on which the trolley wheel can run. The strip *d* is attached to the castings by means of screws, so that it can be easily renewed when worn out. Two terminals for attaching feeder wires are shown at *g*.

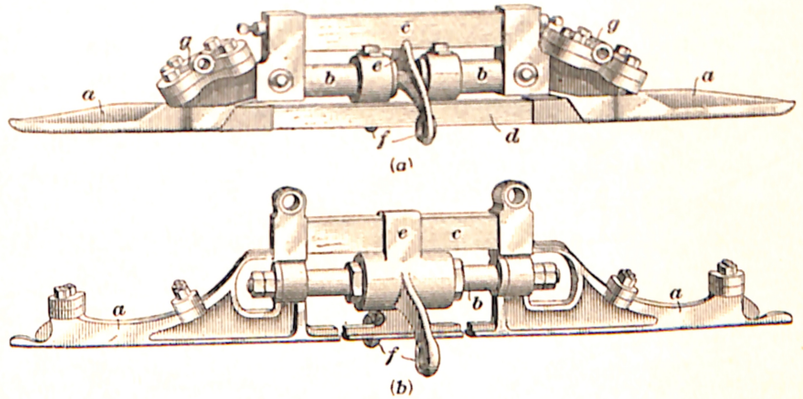


FIG. 25

In some types of section insulator the wooden strip *d* is done away with, and the trolley wheel runs on an extension piece

cast on to the coupling *e*. This extension piece does not make contact with the end castings, short air gaps being left, over which the trolley wheel jumps. A section insulator of this type is shown in view (*b*), which is lettered similarly to view (*a*).

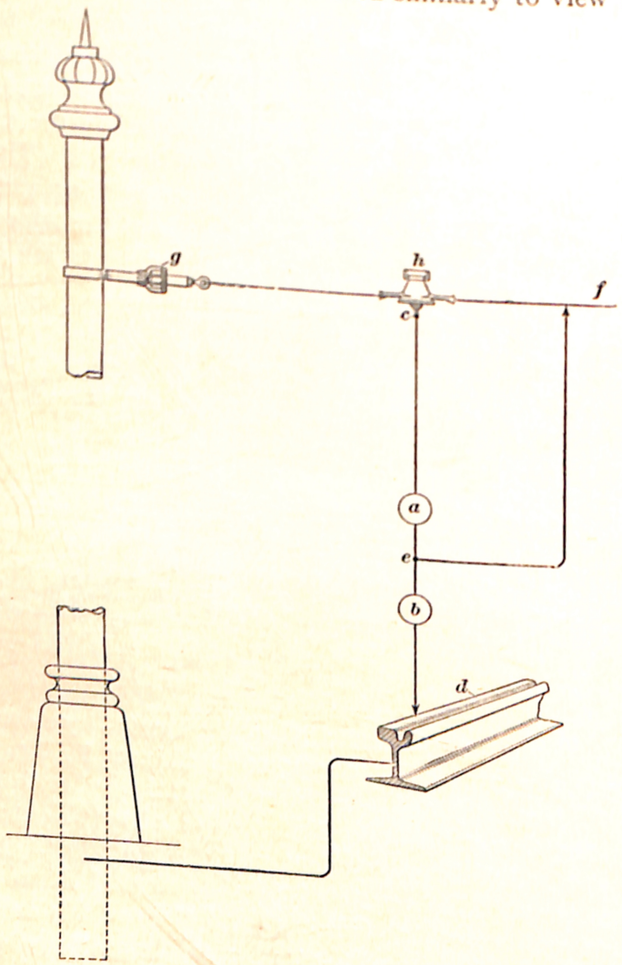


Fig. 26

36. Testing Insulating Fittings.—The Board of Trade regulations require that all overhead insulators shall be inspected and tested once a month. This testing can readily be done by

means of two voltmeters, each reading to 500 volts. These voltmeters *a*, *b*, Fig. 26, are connected in series between the trolley wire *c* and the rail *d*. The middle point *e* between the two voltmeters is connected to the span wire *f*. If the two voltmeters are similar, both will read one-half the line voltage if the insulation of both the strain insulator *g* and the hanger *h* is sound. If the insulation of the strain insulator *g* is defective, there will be a circuit from the span wire *f* to the rail *d* by way of the defective insulator and pole. The voltmeter *b* will therefore be short-circuited and will read zero, while the voltmeter *a* will read the full line pressure. By tracing out the circuit, it will be evident that, if the insulated bolt in the hanger *h* is defective, voltmeter *a* will read zero and voltmeter *b* will read the full line voltage.

37. In order to make these tests rapidly, a contact-maker, known as a **flipper**, is sometimes attached to the trolley arm of the first car to be driven over the route in the morning. The construction and action of this flipper are shown in Fig. 27.

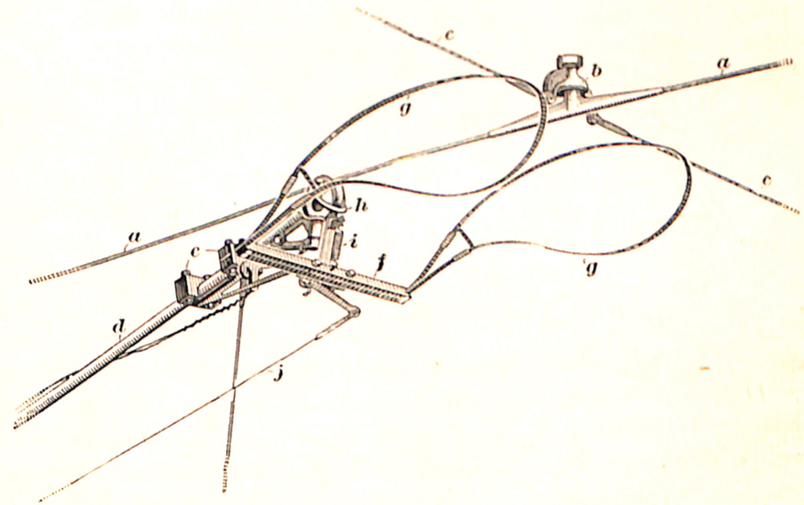


Fig. 27

The trolley wire *a* is supported by the pull-off and ear *b* from the span wire *c*. Fixed to the trolley arm *d* by clamps *e* is a light aluminium framework, to which a wooden rod *f* is attached by means of a pivot passing through its middle point. This

rod carries two loops *g* of thin steel ribbon, and is coupled to the swivelling trolley head by the metal fork *h*, so that it keeps always at right angles to the trolley wire. The rod *f* and steel loops *g* are normally kept in a raised position by the spring *i*, but can be pulled down out of action by the cord *j*. When the steel bows are raised, they *flip* against, or make momentary contact with, each span wire on both sides of the hanger or pull-off.

38. An insulated wire is carried down the trolley arm *d*, Fig. 27, in order to connect the steel loops *g* to the voltmeter inside the car. It is not usual to employ two voltmeters and test both strain insulators and hangers at once; one set of insulators is tested as the car runs out, and the other set on the return journey. The voltmeter is provided with a simple change-over switch, by means of which either set of insulators can be tested without altering connecting wires. The connections are shown in diagrammatic form in Fig. 28, where *a* is the trolley wire, *b* the span wire, *c* the trolley wheel, *d* the steel contact loops, *e* the voltmeter, *f* the change-over switch, and *g* the track rail. When the change-over switch *f* is on contact *1*, the voltmeter *e* will not deflect unless the strain insulator is faulty, and when the switch is on contact *2*, the voltmeter deflects when the hanger or pull-off is faulty. On account of the exceedingly short duration of the contact between the span wire and contact loops when the car is running at 7 or 8 miles per hour, the voltmeter used must be sensitive in order to give any appreciable deflection in the time. It is usual to employ a voltmeter which will give a deflection right over its scale with a pressure of one-fifth of the full line voltage.

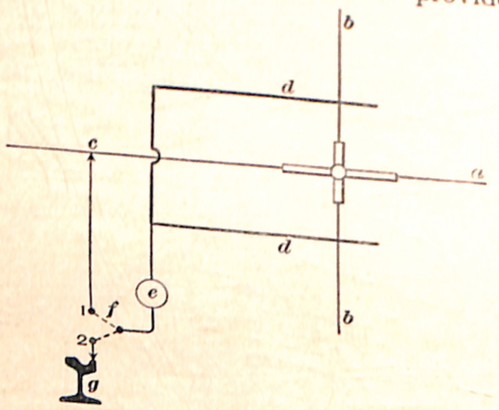


FIG. 28

FROGS AND CROSSINGS

39. Necessity for Frogs.—At the point where one line branches from another, overhead switches, or **frogs**, are used to guide the trolley wheel from one wire to the other. The construction of these frogs depends on whether the holder of the trolley wheel which is used to collect the current is rigidly attached to the trolley pole, or is free to move about a vertical axis while the trolley pole remains stationary. The former type of trolley wheel and holder is known as a *fixed trolley head*, and the latter as a *swivelling trolley head*. When fixed trolley heads are used,

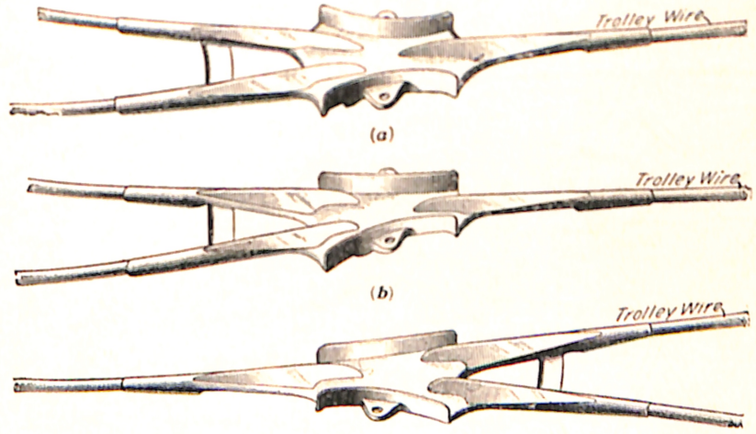


FIG. 29

the system must be arranged for centre-running, and the trolley pole and wheel will follow the car. With a side-running system, it is necessary to use swivelling trolley heads, and unless the frogs on the overhead work are specially constructed, it is quite possible that the car will take one direction and the trolley wheel the other.

40. Frogs for Fixed Trolley Heads.—In Fig. 29 (*a*) is shown the under side of a simple two-way **V** frog of a type that is largely used; (*b*) is a right-hand frog and (*c*) a left-hand frog. In these frogs the trolley wire is soldered into the ears. Fig. 30 shows

a **V** frog in its natural position. In this case the trolley wire is held by clamps *b*, and no solder is necessary. The span wire is attached to the ears *a*.

41. As frogs must be placed correctly with relation to the track, mechanical fastenings for the wires are desirable because they allow the frog to be adjusted to the position that gives the

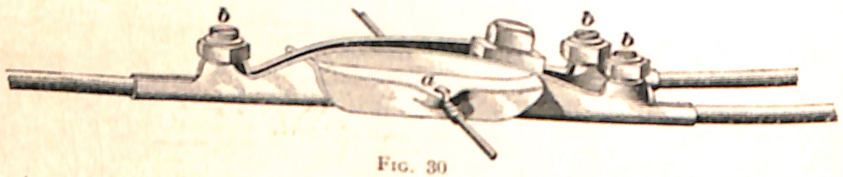


Fig. 30

best results. The satisfaction that any frog will give depends a great deal on how it is put up. If level, the trolley wheel is very likely to follow the direction of the car, but if allowed to sag on one side, it will always give trouble by throwing the trolley wheel off the wire. The position for the frog may be found by the method shown in Fig. 31, where *a* and *b* are the main-line tracks, *c* and *d* the branch-line tracks, *a' b'* the main trolley

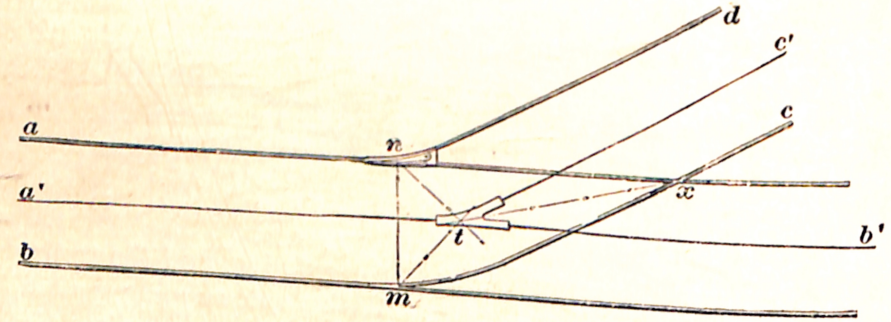


Fig. 31

wire, and *t c'* the branch trolley wire. The centre of the triangle *n x m* will be at a point *t* where the lines bisecting each angle meet ; this determines the position of the frog. It will be a little removed from the centre lines of the tracks. In practice it is often found necessary to adjust a frog after it has been put up. Lateral adjustment can be obtained by means of the turnbuckles attached to the span wires. When a frog is first connected, the trolley wire should be left long and the end coiled

up on top of the frog, so that the latter can be shifted forwards or backwards in case such adjustment is necessary.

42. **Frogs for Swivelling Trolley Heads.** — For swivelling trolley heads, two types of frogs, known as **trailing frogs** and

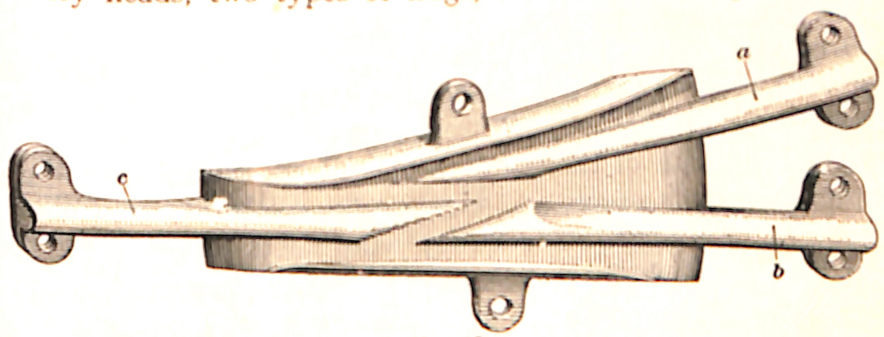


Fig. 32

movable, or mechanical, frogs, are used. Trailing frogs are used where the trolley wheel has to pass from a branch on to the main line. There is only one wire that the trolley wheel can run on

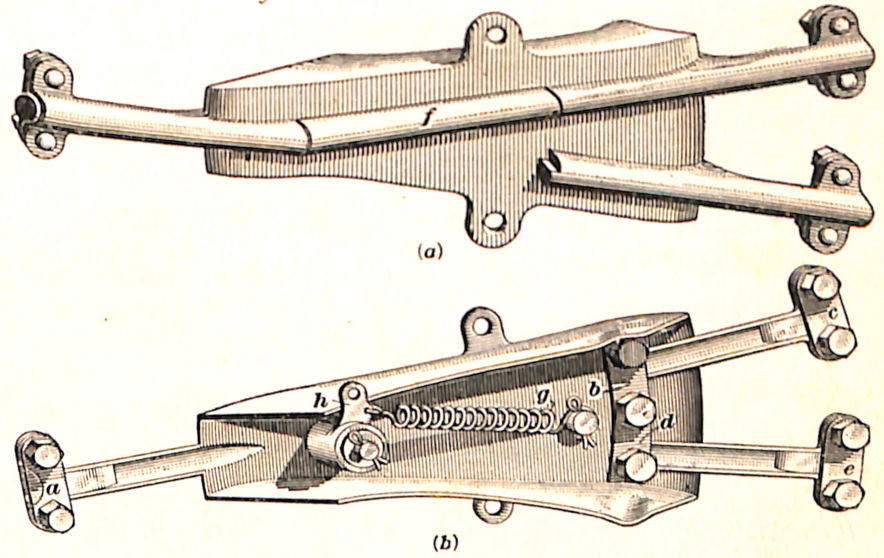


Fig. 33

to. In construction it resembles frogs for fixed trolley heads, and is shown in Fig. 32. The trolley wheel can pass from either branch line *a*, *b* to the main line *c*. The chief difference between this type of frog and that used for fixed trolley heads is that the

open space in the centre of the frog is much larger in the latter type.

43. Movable, or mechanical, frogs are used where the main trolley divides into two or more branches, and are fitted with a movable tongue to guide the wheel on to the proper wire. A two-way mechanical frog is shown in Fig. 33. The tongue is operated by a steel wire suitably insulated and carried down the nearest pole to the footpath, from which position it is operated by the conductor of the car or a special pointsman. View (*a*) shows the running face, and view (*b*) the method of controlling the movable tongue. One trolley wire passes straight through the frog and is held by the clamps *a*, *b*, and *c*; the branch wire is secured by the clamps *d* and *e*. The tongue *f* of the frog is held in the branch position by the spring *g*. The thin steel wire for turning the tongue to the straight-through position is attached to the lever *h*. In some systems the frog is worked automatically by the trolley pole of the car going round the curve operating a lever which moves the tongue; in other systems a special contact is provided on the controller of the car, which energizes an electromagnet controlling the tongue of the frog.

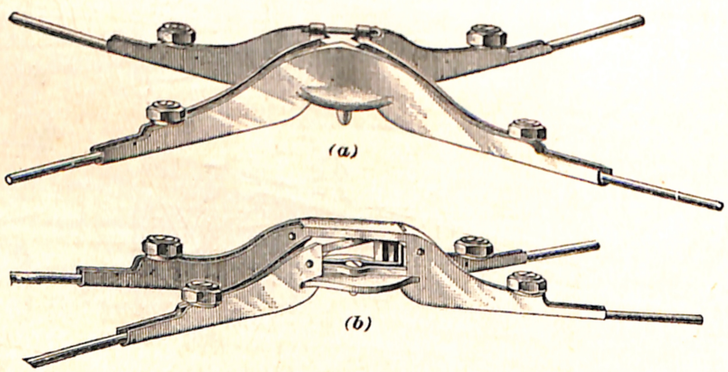


FIG. 34

44. Crossings.—At the point of intersection of two trolley lines, a device called a **crossing**, or **cross-over**, is used. Two common forms are shown in Fig. 34. That shown in (*a*) is used where the two lines cross at right angles, and that in (*b*) where

they cross at an acute angle. Crossings of this type do not insulate from each other the two intersecting trolley wires, and on this account they are called **uninsulated crossings**.

45. As trolley wires must be capable of division into ½-mile sections, when uninsulated crossings are employed, section insulators must be used in conjunction with them, as shown in

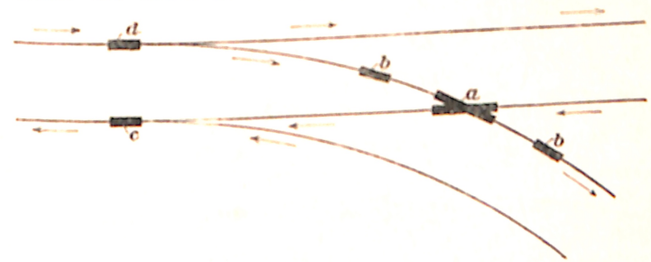


FIG. 35

Fig. 35, where *a* is the uninsulated crossing, and *b* the section insulators. A fixed frog is used at *c*, and a movable one at *d*. The directions of travel of the trolley wheels on the wires are shown by the arrows.

46. Where the angle of crossing is between 75° and 90°, **insulated crossings** can be used. A crossing of this type is

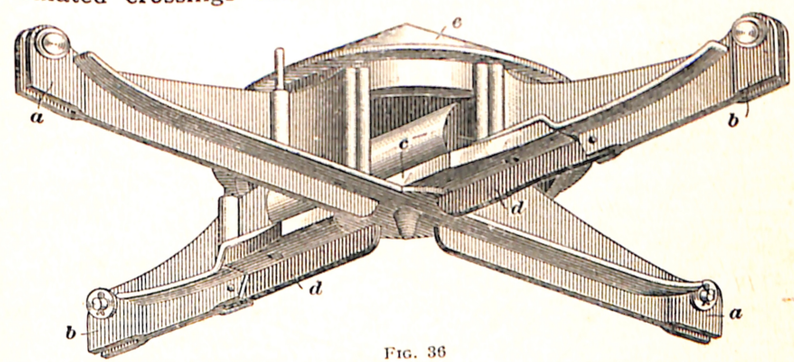


FIG. 36

shown in Fig. 36. The ends of one trolley line are attached to the lugs *a*, which form part of one continuous casting. The ends of the other trolley line go to the lugs *b*, which are insulated from each other by the wood or fibre insulation *c*. These lugs *b*

are provided with extension pieces *d* of insulating material on which the trolley wheel runs. The whole is protected by the fibre cap *e*. These crossings are only suitable for large angles at the intersection of the trolley wires; for narrow angles, uninsulated crossings in conjunction with section insulators must be used.

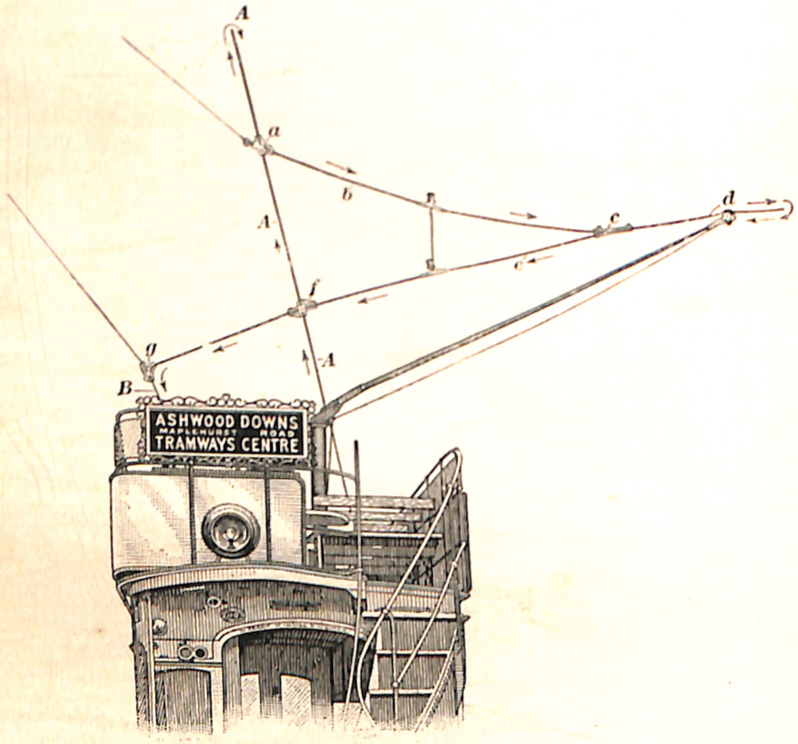


FIG. 37

47. Trolley-Arm Reverser.—When a car reaches a terminus, it is necessary to change the trolley arm from one wire to the other and to turn it round so that it trails behind the car. With the type of overhead construction usually adopted, this is effected by pulling down the trolley arm by means of a rope, swinging it round, and allowing it to rise again with the trolley wheel under the correct wire. If the terminus is not well lighted

at night, it is often a difficult matter to get the wheel on the wire, and in addition involves leaving the car in darkness while the change is made.

48. To avoid these disadvantages, a special combination of frogs and crossings, as shown in Fig. 37, is sometimes adopted to reverse the trolley arm. This arrangement needs no attention from the conductor and the lights on the car do not go out while the trolley is reversing. The car, in coming into the terminus (toward the observer), uses line *A* until it passes the fitting *a*. On being reversed, the car travels away from the observer, and, passing over fitting *a* in the opposite direction, the trolley wheel is shunted by it on to the wire *b*, from which it passes over the fitting *c* on to the wire *d*. The trolley arm is then reaching out to its full extent, at right angles to the car. As the car proceeds, the trolley wheel returns along the wire *d* and again crosses fitting *c*, which shunts it on to wire *e*. It runs over the crossing *f*, and is turned by fitting *g* on to the trolley wire *B*. The trolley arm is then trailing in its correct position for the return journey.

ERECTION OF OVERHEAD WORK

TOWER WAGONS

49. Construction.—For erecting and repairing the trolley wire and overhead fittings, a **tower wagon** is employed. This consists of a platform raised on a staging, the whole being mounted on a special wagon, so that work may be done on the overhead wire and equipment without the use of ladders. The height of the platform is often adjustable by means of gearing, so that the work may be done in the most convenient way. In some types of tower wagon, the tower is mounted on a wagon drawn by horses, and in others it is mounted on a motor wagon. The latter type, shown in Fig. 38, is very useful in the case of breakdown, where repairs are urgently necessary. The height of the working platform *a* can be adjusted by means of the gearing *b*.

In many tower wagons, the base of the tower is filled in with

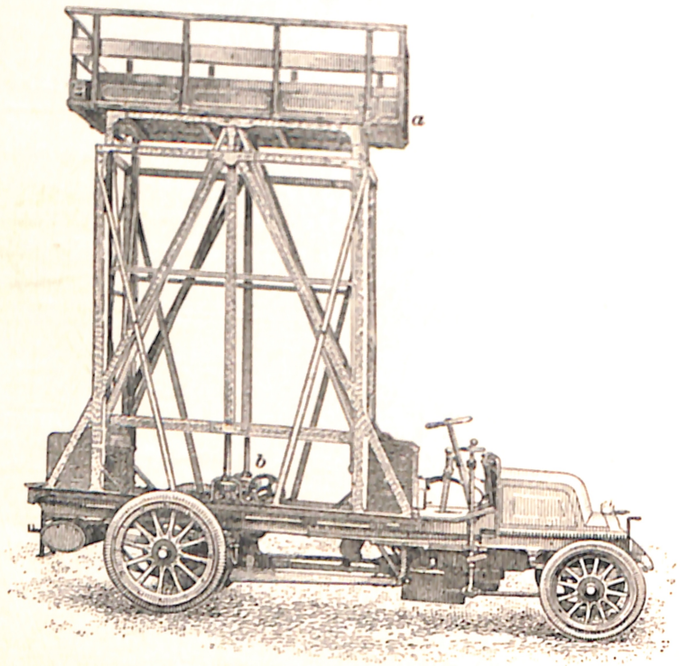


FIG. 38

tool boxes, in which are carried the tools and spare fittings, so that repairs can be executed in the shortest possible time.

SUSPENSION OF SPAN AND TROLLEY WIRES

50. Suspension of Span Wire.—After the poles have been erected and allowed to set, the span wire is stretched into position, the necessary tension being obtained by means of a device called a **screw coupling**, or **pulling jack**, which is attached to the wire by a special clamp, known as a **come-along clamp**. A screw coupling, or pulling jack, shown in Fig. 39 (*a*), is similar in construction to a turnbuckle, but much more massive. The two screw hooks *a*, *b* are provided with right- and left-hand screw threads and are drawn together by turning the rod *c*. The

ends of the rod are provided with flattened surfaces *d* to enable them to be gripped by a wrench.

A come-along clamp, shown in Fig. 39 (*b*), is composed of three steel links *a*, *b*, *c* pivoted together at *d* and *e*. The wire to be gripped is inserted between the jaw on one link *b* and a projection on another link *c*. When a pull is exerted on the third link *a* by means of a rope passing through the eye, the

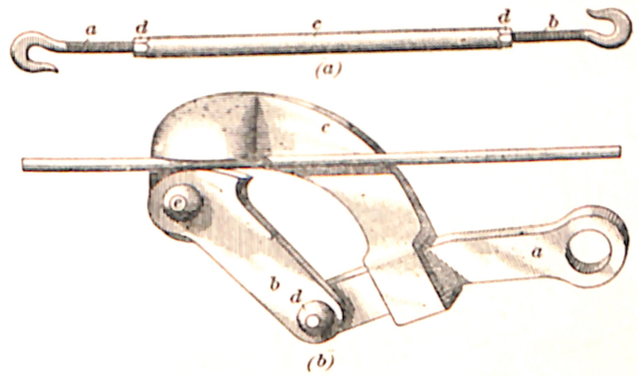


FIG. 39

jaw of link *b* moves upwards and firmly clamps the wire. The greater the pull on the link *a*, the more firmly is the wire gripped. For erecting the very short span wires often used with the bracket-arm construction, these tools are not required, sufficient tension being obtainable by the use of an insulated turnbuckle or Brooklyn strain insulator.

51. Suspension of Trolley Wire.—When the span wires are in position, the trolley wire is suspended. This is usually supplied on drums, each holding $\frac{1}{2}$ or 1 mile of wire, which are mounted on a special reel wagon, which precedes the tower wagon by about 40 yards. The end of the trolley wire having been securely anchored to a terminal post, the wire is passed over the tower wagon and both tower wagon and reel wagon move forwards, the tower wagon stopping at each cross-span and attaching the wire temporarily with a binder or an **S**-shaped iron hook to the span wire or bracket arm. When the wire is all run out, it is stretched to the desired tension by means of

pulley blocks or a screw coupling, used in conjunction with a come-along clamp. At curves, temporary anchor wires are attached, and the whole section is tightened and adjusted several times before the permanent attachment of the trolley wire to its supports is commenced.

52. Permanent attachment is usually made first at curves, the trolley wire being held in a **soldering clamp**, the construction of which is shown in Fig. 40. This clamp consists of an iron frame *a* provided with jaws *b*, which can be made to clamp the wire by means of the handles *c*. The clamp is usually attached to the trolley wire with the bar *a* above the wire, which is given a half twist by bringing the clamp into the position shown in Fig. 40. The wire is then well cleaned and tinned with solder, and the ear soldered to it with the screwed stem downwards. This allows the solder to be easily poured into the ear. The joint is then carefully smoothed off with a fine file and emery paper, and the clamp is returned to its first position, so that the stem of the ear is upwards, ready for attachment to the hanger or pull-off.

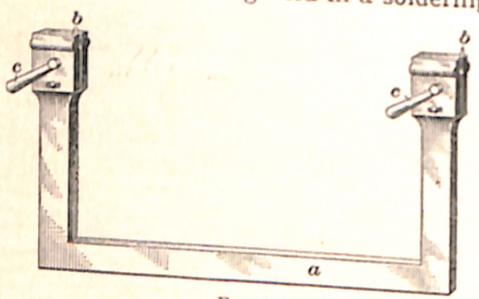


Fig. 40

53. Tension on Trolley Wire.—In putting up trolley wire, judgment must be used regarding the tension put on it. Thus, wire strung in hot weather must be allowed more sag than that put up in cold weather, otherwise the contraction will put severe strains not only on the trolley wire itself, but on the whole overhead construction. A range of 45° C. between summer and winter temperatures will correspond to a variation of nearly 4 feet per mile in the length of the trolley wire. For a 120-foot span of No. 0 B. & S. wire, put up with a tension of 2,000 pounds, the sag at the centre of the span will be 3·6 inches; for a tension of 1,500 pounds, 5 inches; for 750 pounds, 9·5 inches; for 500 pounds, 15 inches. Dawson recommends, as a safe

allowance for localities where the temperature does not fall below about —10° C., a sag equal to three-fourths of 1 per cent. of the span when the wire is strung at the ordinary temperature of from 15° to 18° C. Thus, for a 120-foot span, a sag of about 10·8 inches would be allowed, and in the warmest weather the sag would not exceed 15 inches.

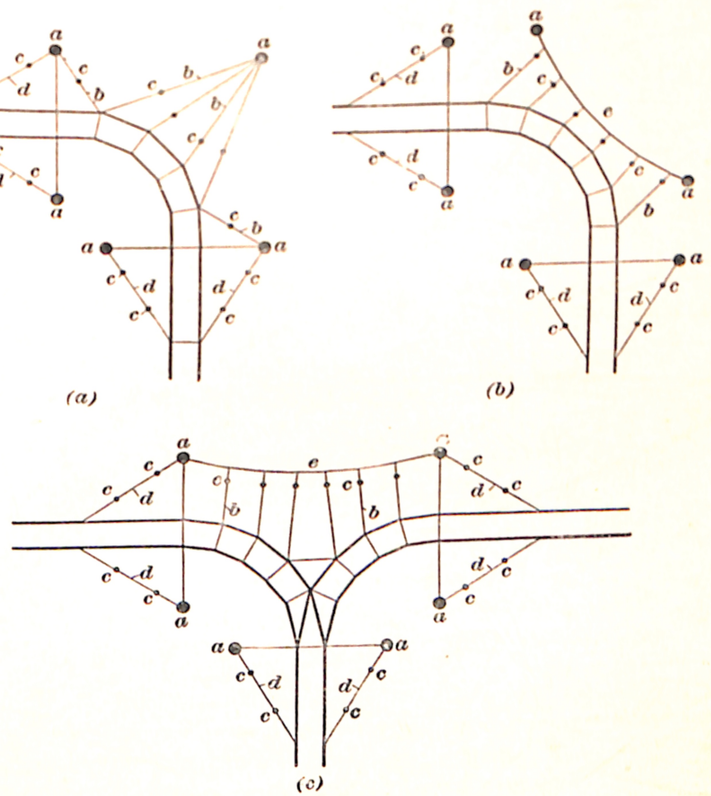


Fig. 41

54. Construction at Curves.—The methods of securing the trolley wires at curves are shown in Fig. 41, in which *a* are the poles, *b* the pull-off wires, and *c* the strain insulators. In (*a*), the trolley wires are anchored on each side of the curve by anchor ears, which are attached to the anchor wires *d*. View (*b*) shows another arrangement, in which the pull-off wires *b* are attached

to a stout span wire *e* stretched between the poles *a*, *a*. The anchoring arrangement is the same as in view (*a*). In view (*c*) is shown the arrangement adopted at a double curve.

55. Offset in Trolley Wire.—When erecting an underrunning system for use with a fixed trolley head on curves, the trolley wire is not suspended exactly over the centre line of the track, but is shifted toward the inside rail by a distance that depends on the radius of the curve, the height of the wire, and the length of the trolley arm. This departure from the centre line of the track is shown in Fig. 42, where the curve *r* is the centre line of the rails and *t* the path of the trolley wire. The amount of offset measured at the middle of a 90° curve at the point indicated by the arrows in Fig. 42 should be approximately as shown in Table VI. The object of the offset is to allow the trolley wheel to lie closely to the wire, which it would not do if the wire followed the centre line of the track, as the wheel would lie diagonally across

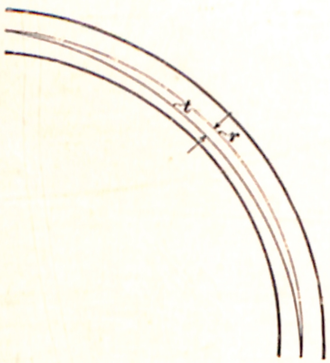


FIG. 42

TABLE VI

OFFSET IN TROLLEY WIRE

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

the wire and cause a large amount of wear on curves. Where a swivelling trolley is used, considerable latitude may be allowed, and the trolley wire may be several feet from the centre line of the rails on curves.

ELECTRICAL CONSIDERATIONS

SUPPLY AND CONTROL OF CURRENT TO TROLLEY WIRES

FEEDERS

56. The **feeder system** includes all the cables necessary to distribute the current from the generating station or substation to the working conductors; in the overhead system it consists of the trolley wires and the track rails. In compliance with the Board of Trade regulations, the trolley wire is divided into ½-mile sections insulated from one another, and the connection with the feeder system is usually made at the centre or ends of each section.

In the conduit system, which has an insulated return, the negative feeders are duplicates of the positive feeders; but in the overhead system, which has an earthed return, the negative feeder system differs from the positive, and requires separate consideration. In Great Britain, feeder cables are laid underground, but in America, on the Continent, and in the Colonies they are run overhead. They usually follow the line of track, but considerable saving may sometimes be effected by taking a short cut between the power station and the feeding point; this means not only a saving in the cost of the feeder, but also in the watts lost in transmission. Any of the standard types of underground mains may be used for feeders.

57. Feeder Pillars.—The positive feeder terminates on a small switchboard placed in a cast-iron box, called a **feeder, or switch, pillar,** which is placed on the footpath near the point at which connection is to be made to the trolley wire. The short feeders connecting the main feeder with the trolley wire are

called line taps, or side feed-cables. They are usually drawn inside one of the poles used for supporting the trolley wire; and from the pole they pass along either the bracket arm or span wire to a feeder ear attached to the overhead wire. These line taps are connected to a feeder bus-bar in the switch pillar through trolley switches, which are used when necessary for cutting the current off the overhead wire.

A typical tramway feeder pillar, arranged for feeding at the section insulators, is shown in Fig. 43, (*a*) being the front view

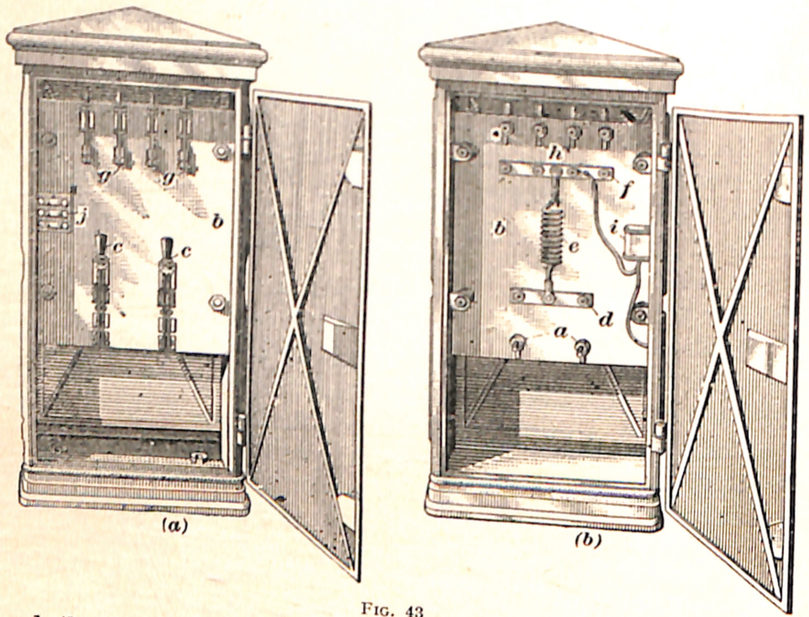


FIG. 43

and (*b*) the back view. The incoming feeders from the power station are connected to the terminals *a*, which pass through the slate slab *b* to the lower terminals of the switches *c*. When these switches are closed, they connect the feeders to the bus-bar *d*, which is connected through the choking coil *e* of the lightning arrester to the bus-bar *f*. The bottom contacts of the trolley switches *g* are connected to this bus-bar *f*, and the top contacts are provided with sockets *h*, into which the side feed-cables are sweated. Any side feed-cable can thus be connected

to the feeder bus-bar by closing its switch. A lightning arrester *i* is connected to the bus-bar *f*, while a terminal board *j* is provided for telephone or pilot wires. The feeder pillar is fitted with doors at front and back, so that the switches and connections are easily accessible. The doors are kept locked, so that no unauthorized persons can have access to the connections.

58. Methods of Feeding.—The simplest method of feeding is to connect the trolley wires with the bus-bars in the power station *a*, Fig. 44, by means of short feeders b_1, b_2, and provide switches d_1, d_2, etc., at each section insulator, the overhead wire serving the purpose of both feeder and working conductor. Such a method is of course only suitable for a light service. The switch boxes d_1, d_2, d_3, d_4, d_5, d_6 are fixed to the poles and are connected to the trolley wires by means of the side feed-cables *e*, *e*.

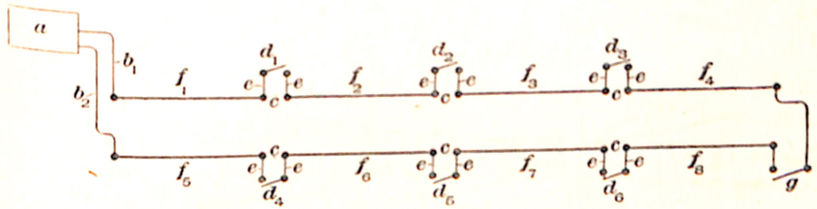


FIG. 44

When a switch d_1 is closed, the current is conveyed from the section f_1 to the section f_2. A switch must also be placed at the end *g* to connect the two wires in parallel, so as to reduce the drop in the line. This switch is also necessary if it is desired to cut the current off one $\frac{1}{2}$-mile section; with no switch at *g*, if the switch d_1 were opened, the current would be cut off the three sections f_2, f_3, and f_4, whereas, with a switch at *g*, the current could be cut off the section f_2 by opening the switches d_1 and d_2.

59. Where the drop in the line would be too great to adopt the method just given, the arrangement shown in Fig. 45 might be employed. In this case a feeder runs from the power station *a* to the point *h*, feeding the sections f_3 and f_7. The current will be conveyed to the next sections f_4 and f_8 by means of the section switches d_3, d_6. The additional feeder might be connected to work in parallel with the short feeders b_1 and b_2 by closing section

switches d_2 and d_3, or it might be insulated from them at h, and the short feeders b_1, b_2 left to deal with the sections of trolley wire f_1, f_2, f_5, f_6. Under ordinary service conditions, it is advisable to separate the feeders in order to more easily locate defects,

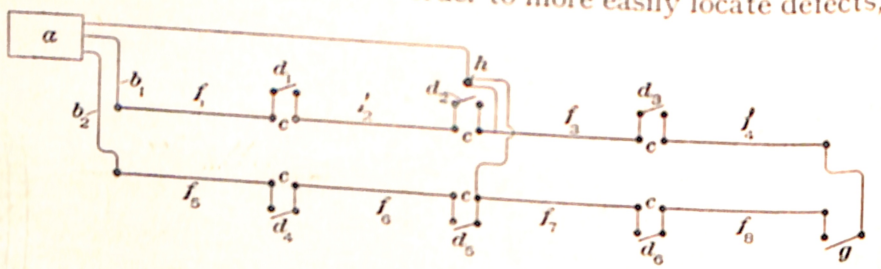


FIG. 45

but on special occasions of heavy load it should be possible to join the feeders in parallel.

60. In the case of a very heavy service, it might be necessary to run distributing cables from the main feeders to other feeding points, so as to reduce the drop, in volts, in the trolley wire. In the arrangement just shown, the feeder is supplying the trolley wire at the section insulators, but this arrangement is not always adopted ; the feeder and distributor boxes are sometimes placed at the centre of the $\frac{1}{2}$-mile sections. In Fig. 46 (*a*) is shown a typical $1\frac{1}{2}$ miles of tramway fed from one feeder, the side feed-cables being connected to the section insulators ; view (*b*) shows a similar route with the side feeds connected to the centre of the sections. In each case, *a a'*, *b b'*, and *c c'* are the three $\frac{1}{2}$-mile sections of double-track trolley wire, which are supplied by the feeder *d*. The feeder switches are lettered *e*, the interconnecting switches *f*, the distributor switches *g*, and the trolley switches *h*. The distributing cables are shown at *i*, and the section insulators are indicated by the openings *j* in the trolley line.

For economy in transmission, the method of feeding into the section insulators is preferable, for the trolley wire is in parallel with the distributing cable and so helps in distributing the current to the next section. The advantages of feeding into the centres of the sections are that the number of side feed-cables and trolley switches is reduced by one-half, and consequently the trolley switches are more easily understood and handled by

non-technical traffic inspectors. In order to have the feeder *d* disconnected from the adjacent feeders when it is feeding into the section insulators, it is necessary to leave open both centre trolley switches and the interconnecting switch in each end feeder

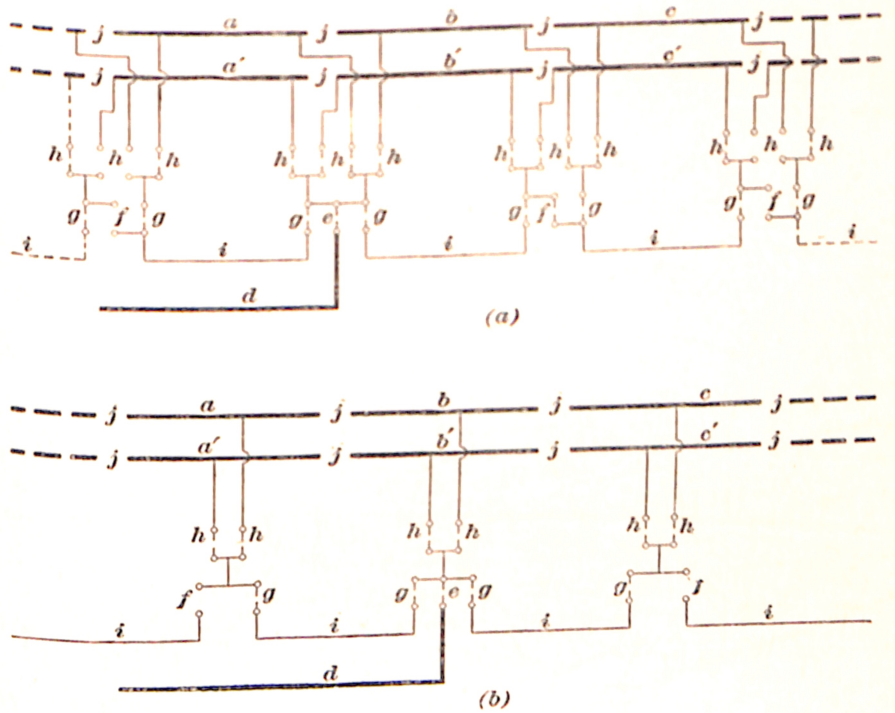


FIG. 46

pillar. When feeding into the centre of the circuit, it is only necessary to leave open the interconnecting switch *f* in each end feeder pillar to disconnect feeder *d* from the adjacent ones. If the various feeders are to be connected through fuses, the fuses will be inserted in place of the interconnecting switches.

POSITIVE BOOSTERS

61. Functions of Positive Boosters.—When some of the sections of a tramway are situated a considerable distance from the power house, it is necessary, in order to avoid the use of a large amount of copper in the feeders, to use feeders of small cross-section, and to compensate for the voltage drop in them by the

use of a positive booster. A positive booster is a generator connected in series with the feeder or feeders on which the voltage is to be raised, in such manner that the voltage that it generates is added to that of the main generators, thus increasing the voltage applied to the feeders by the amount of the pressure generated by the booster. In Fig. 47, *a* represents the armature of the main generator and *b* the booster armature. Short feeders supplying sections close to the power house are connected to the + bus-bar of the generator in the usual manner, and long feeders are connected to the + bus-bar through the booster.

62. For tramway work, boosters are nearly always of the series type; that is, the field winding is connected in series with the armature. The machines are so designed that the voltage generated increases in proportion to the current that passes

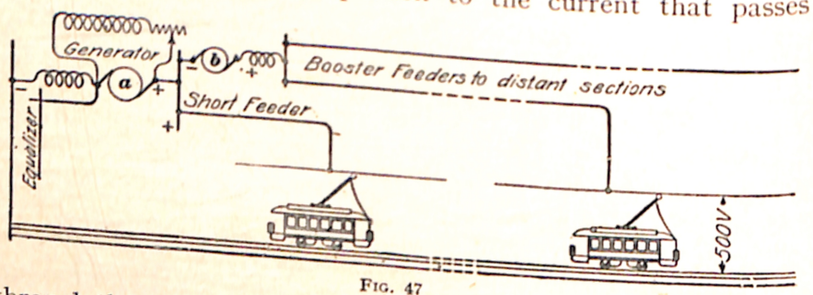


FIG. 47

through them. Thus, when the load on the long-distance feeders is light, the booster voltage is low because the field is weak. When a heavy load comes on, the booster voltage increases and automatically compensates for the drop in the long feeders supplied through the booster. If the booster were shunt- or compound-wound, and thus generated a practically constant voltage regardless of the current supplied over the feeders, an excessive voltage would be applied to the cars at light loads because there would then be little loss in the line to take up the booster voltage.

63. Methods of Driving Boosters.—Boosters are nearly always driven by means of shunt-wound motors, which run at a practically constant speed. They can also be driven by steam engines or any other convenient source of power, but in most

tramway stations it is very convenient to use shunt motors supplied from the mains. Boosters do not differ in their general construction from other direct-current generators, except that their commutators are often longer than on standard generators on account of the large current that they carry in proportion to their size.

64. Output of Boosters.—The output of a booster, in watts, is equal to the product of the number of amperes passed through the booster and the number of volts by which the pressure is raised. Thus, if a booster carries 600 amperes, and if when this current is passed through it 100 volts is generated, the output of the booster is $600 \times 100 = 60{,}000$ watts, or 60 kilowatts. If the current dropped to 300 amperes, the voltage generated would, since the booster is series-wound, drop to about half the full-load voltage, that is, to 50 volts, and the output would then be $300 \times 50 = 15{,}000$ watts, or 15 kilowatts. Thus, the loss in the line is compensated for automatically and the voltage at the cars remains nearly constant notwithstanding fluctuations in load.

The booster output for any given case will depend on the current to be carried by the feeders that require boosting, and also on their resistance. In Great Britain, feeders of any great length are seldom used, as large tramway systems are supplied from substations, to which power is transmitted by high-tension alternating current. The alternating current is converted to direct current in the substation, which supplies a comparatively small area. A series booster is often provided with a *diverter*, that is, an adjustable resistance in parallel with the field winding, which can be used to divert some of the current from the winding, and thus reduce the voltage generated by the booster.

65. Booster Connections.—A booster must always be connected in series with the feeder or group of feeders in such manner that its voltage will be added to that of the main generators. Thus, the — terminal of the booster must be connected to the + bus-bar of the generator. Fig. 48 shows a plan of connections for a motor-driven booster. The main generators *1*, *2*, *3* are connected to the + bus-bar in the usual manner,

and the + bus-bar is connected to the — booster bus-bar through switch *a*. Each feeder is provided with a double-throw single-pole switch *b*, by means of which it can be connected either to the main + bus-bar or to the + bus-bar of the booster. As indicated by the dotted lines, the long feeders *A*, *B* are connected to the booster, while the short feeder *C* is supplied with

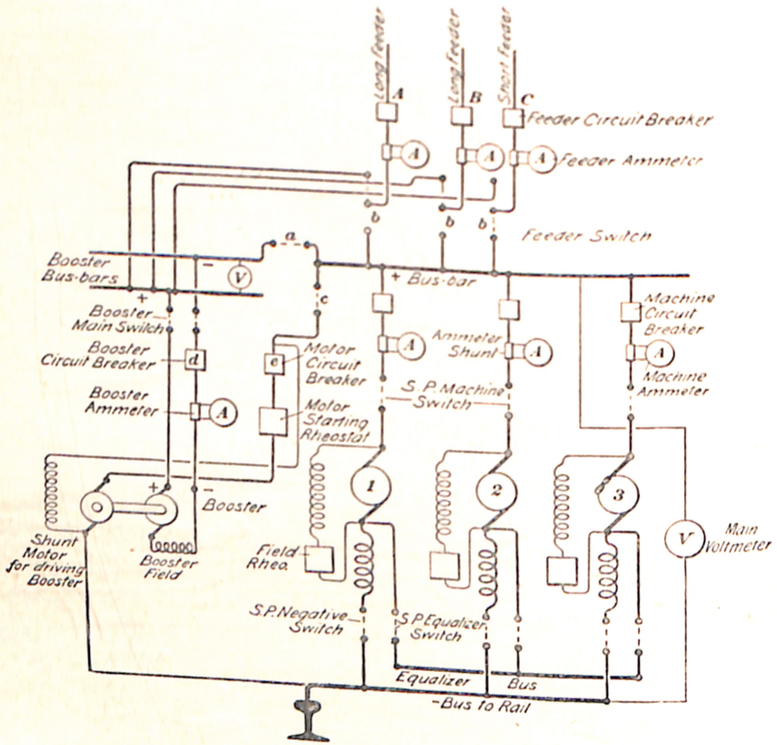


FIG. 48

current directly from the main generator. The booster is driven by a shunt motor supplied with current from the main generators, and equipped with a circuit-breaker and starting rheostat. The booster is connected to the booster bus-bars through an ammeter, circuit-breaker, and double-pole main switch.

66. By following out the connections in Fig. 48, they will be found to be equivalent to the elementary connections in Fig. 47.

All current supplied to feeders *A* and *B* passes through the booster, and the voltage applied to them is increased by an amount proportional to the current. The motor circuit-breaker should be arranged so that in case it opens the motor circuit the current will also be cut off from the booster. The simplest way of doing this is to mount the two circuit-breakers *d*, *e* side by side and have them interlocked, so that when the motor circuit-breaker *e* flies out, the booster circuit-breaker *d* will also open. They should also be arranged so that the booster circuit-breaker *d* cannot be closed until after the motor has been started. If current were cut off from the motor, but not from the booster, the latter would be driven as a series motor, and an unloaded series motor on a constant-potential circuit will race badly. If, therefore, the current is not shut off promptly damage may result. The diagram in Fig. 48 shows how boosters are connected when not worked in conjunction with a storage battery. In a large number of substations, however, storage batteries are employed.

ECONOMICAL USE OF FEEDERS

GENERAL CONSIDERATIONS

67. Distribution of Load. — It is impossible to lay down general rules, for calculating the most economical amount of copper to install and the best method of disposing of that copper to meet the requirements of a given tramway service, that will apply to all cases and conditions. The present practice of dividing the line into insulated sections has, however, simplified the work of calculation, because each section can be considered as an independent line governed by its own local conditions of load. If these conditions could in any case be laid down with certainty, the problem for any particular case would be solved; but that solution would be of little use to the engineer for application to other cases, because it is almost impossible to find any two systems, or even any two sections of the same system, that have the same conditions of load, and therefore require the same distribution of copper. During one part of the day the

heaviest load might be on one part of the line, and later in the day it might be on a section several miles away.

68. In addition to this, there may take place gradually a general shifting of the load more serious than a daily or weekly change, due, possibly, to changes of attractions from one end of the line to the other, or by a shift in the field of suburban improvements. Although the system may be designed in such a way that it meets satisfactorily almost every requirement of the present service, subsequent changes, such as the development of suburban property, may throw it completely out of balance. The only thing to do then is to install new feeders where they are needed. It is now a well-known fact that it is not economical to spend too much in cables, although they may be placed with good judgment from an electrical point of view, and successfully fulfil their function of raising the voltage to its normal value at the desired point. Cables are expensive, and in the effort to lessen the loss in the line, it is an easy matter to spend so much on them that a condition arises when the money invested in cables might be more profitably invested in other ways, as, for example, in the installation of boosters or storage batteries.

69. Installation of Feeders.—The points that must be kept in view when considering the installation of new feeders are as follows: By reducing voltage drop, a certain amount of energy is saved, and the saving in watts or horsepower can be approximately calculated. From a knowledge of what it costs to produce a unit of energy at the power station, the direct saving effected by the increase of feeders can be at once obtained, and by knowing the cost of the additional cables installed, including the cost of construction, the interest on the cost of the copper may be computed. A certain amount must also be allowed for depreciation. Thus, if the life of a cable is 10 years, one-tenth of the difference between the first cost of the cable and its value when replaced must be set aside each year to provide for its replacement. The rule, that it pays to install more feeders if the cost of the watts saved in a year exceeds a year's interest on the cost of the additional feeders installed, together with the allowance

for depreciation, is one that should always be kept in mind. It must not be forgotten, however, that the above limiting condition expressed in the form of an equation (interest on the cost + depreciation = value of energy saved) does not include all the elements that modify the equation.

70. When the feeding system is improved, it brings about a saving in a direct way by reducing the loss in the line and also effects a saving in an indirect way by keeping up the voltage, and thereby increasing the efficiency and speed at which the cars run. This not only decreases the number of cars necessary to conform to the conditions of a given time table, but by improving the service it attracts travel, especially in cases where there is competition. Even in cases where there is no competition, an improvement in the service draws passengers.

Let A = annual interest on cost of feeder;
B = annual allowance for depreciation;
C = value of energy saved, per annum;
D = increase in money taken, due to traffic improvement.

Then, the proper balance is reached when

$$A + B = C + D$$

EXAMPLES OF FEEDER CALCULATIONS

71. Drop in Feeders.—In the transmission of current for electric tramways, as in other cases of electric transmission, the loss or drop in the line is usually limited. If the loss is large, a comparatively high-resistance line with a corresponding small amount of copper can be used, but a large line drop means a low voltage at the cars unless the voltage at the station is automatically increased as the load increases. Low line voltage makes it hard for the cars to maintain their schedule time, thus giving a bad service. It is seldom that the average drop is less than 10 per cent. (50 volts), and in some cases it runs higher than this; if feeding is accomplished through boosters, the line drop may be as great as 100 volts.

72. The weight of the rail is fixed by traffic considerations, and, under the Board of Trade regulations, a rail weighing not

less than 90 pounds per yard must be used, so that an approximate estimate of the drop in the return circuit can be formed at the outset. The balance of the drop will then give that allowed for the feeders, and they should be designed to conform to this as nearly as possible. There is a great difference between the maximum and average loads in the stations, and the smaller the station, the greater is the difference liable to be. For this reason, the average drop and maximum drop may be widely different. For instance, where the road operates only two or three cars, the load fluctuates between zero and the maximum several times in a minute. Before the size can be assigned to the feeders, the average load that each feeder has to look after must be approximately known or ascertained. In doing this, it is very convenient to divide the line into sections, assign to each section the load that probably will be on it, and proportion the feeders accordingly.

TABLE VII

RESISTANCE OF HARD-DRAWN COPPER TROLLEY WIRE

Gauge	Resistance at 15·5° C. Ohm	
	Per 1,000 Yards	Per Mile
0000000 S.W.G.	·1246	·2193
000000 S.W.G.	·1446	·2546
0000 B. & S.	·1473	·2596
00000 S.W.G.	·1669	·2937
000 B. & S.	·1816	·3196
0000 S.W.G.	·1946	·3426
000 S.W.G.	·2251	·3961
00 B. & S.	·2292	·4033
00 S.W.G.	·2572	·4527
0 B. & S.	·2945	·5180
0 S.W.G.	·2967	·5222

73. In order to calculate the voltage drop and feeder sizes, it is necessary to obtain a rough plan of the district to be served and the line of route, and to mark on it the position of all cars in use on the days of maximum traffic. The amperage at any point can then be calculated. In cases of a level road and single-truck cars, an average of from 17 to 20 amperes may be taken, and in the case of large double-truck cars, from 24 to 30 amperes.

On lines with abnormal gradients and curves, special allowance must be made. The average distance between the cars running on the system can be easily found, if the average speed and the frequency of the service are known. For example, if there is a 5-minute service, and the average speed of the cars is 6 miles per hour, it takes 10 minutes for a car to run 1 mile. As there is a 5-minute service, each car must have run ½ mile from a given point before the succeeding car passes the same point; the cars are thus spaced ½ mile apart. Taking the same number of cars on the return journey, and assuming that they are spaced midway between the others, there is a car every ¼ mile. The same method of calculation can be applied to any other speed or service. It does not make any difference to the spacing of cars whether it is a single or double line, provided that there are enough turnouts.

TABLE VIII

RESISTANCE OF SILICIUM-BRONZE TROLLEY WIRE

Gauge	Resistance at 15·5° C. Ohm	
	Per 1,000 Yards	Per Mile
0000000 S.W.G.	·1744	·3071
000000 S.W.G.	·2031	·3574
00000 S.W.G.	·2342	·4123
000 B. & S.	·2601	·4577
0000 S.W.G.	·2733	·4811
000 S.W.G.	·3159	·5561
00 B. & S.	·3289	·5777
00 S.W.G.	·3611	·6356
0 S.W.G.	·4164	·7330

74. The general problem may be stated as follows: Given the size of rails and trolley wire, and the current required at various points, find where positive feeders will be required for the trolley wire and negative feeders for the rails, the size of these feeders, and how the feeder system should be arranged. It must not be forgotten that the maximum drop on the rail return is not to be over 7 volts, and it is better to keep well inside this limit.

75. Resistance of Trolley Wire.—For the purpose of calculating the voltage drop in the trolley wire, it is necessary to know its resistance. This is given for various gauges of hard-drawn

copper, per 1,000 yards and per mile, in Table VII, and similar data for silicium-bronze wire are given in Table VIII.

76. Resistance of Return Circuit.—The resistance of the track rails must be known in order that the rail drop may be calculated. For convenience, the resistances per 1,000 yards and per mile of the British standard sections and their weights are given in Table IX.

77. Resistance of Feeder Cables.—When making feeder calculations, it is convenient to be able to quickly find what section of feeder cable will convey a given current with a given drop of volts per mile. This information is best obtained from curves like those in Fig. 49, which are for cables having sectional areas of copper ranging from ·1 to 1 square inch. The dotted line *a b* shows the limit above which the cable should not be worked on account of heating. For example, suppose it is desired to transmit 400 amperes over 1 mile with a drop of 35 volts. The vertical line from 400 amperes on the horizontal scale will be intersected by a line from 35 volts on the vertical scale on the line marked ·50. The section of cable required is therefore ·5 square inch, and as the point of intersection is below the dotted line *a b*, the cable will safely carry 400 amperes. Had the point of intersection been above the dotted line *a b*, a larger cable with a smaller drop of volts per mile would have had to be used.

TABLE IX

RESISTANCE OF STANDARD TRAMWAY RAILS

British Standard Rail Section Number	Weight Per Yard Pounds	Resistance Ohm Per 1,000 Yards	Resistance Ohm Per Mile
1	90	·0278	·0489
1 *c*	96	·0260	·0458
2	95	·0263	·0463
2 *c*	101	·0248	·0436
3	100	·0250	·0440
3 *c*	106	·0236	·0415
4	105	·0238	·0419
4 *c*	111	·0225	·0396
5	110	·0227	·0400
5 *c*	116	·0216	·0379

78. Simple Voltage-Drop Calculations.—In order to show how the voltage drop is calculated, take first the case of a single track fed from one end only, with two cars taking 20 amperes each at a distance of 3 miles from the power house. The rails used weigh 90 pounds per yard, and there are two No. 000 S.W.G. hard-drawn copper trolley wires in parallel. The resistance per

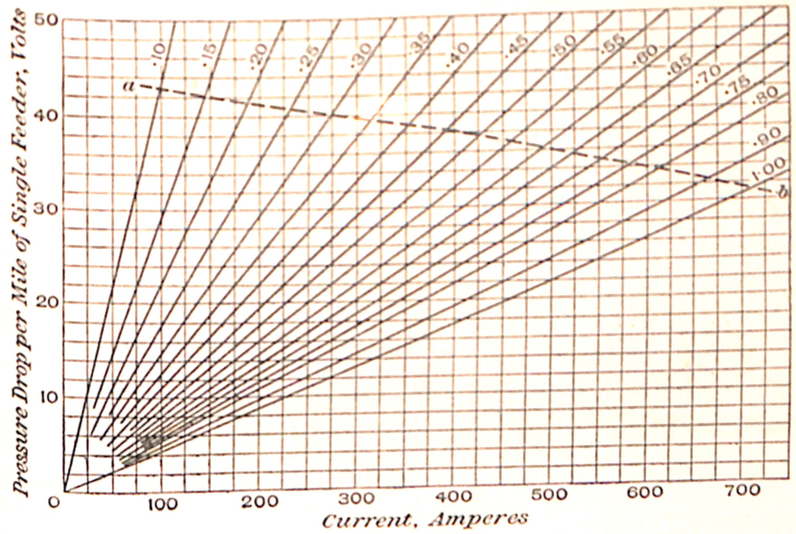


FIG. 49

mile of No. 000 S.W.G. copper trolley wire, from Table VII., is equal to ·3961 ohm. The resistance of 3 miles of single wire is therefore ·3961 × 3 ohms, and of the two wires in parallel is $\frac{\cdot 3961 \times 3}{2}$ = ·59415 ohm. The current taken by the two cars is 2 × 20 = 40 amperes, and the voltage drop in the trolley wires, given by the product of their resistance and the current, is ·59415 × 40 = 23·766 volts. The resistance per mile of single 90-pound rail, from Table IX, is equal to ·0489 ohm, and the resistance of 3 miles of track consisting of two rails in parallel is $\frac{\cdot 0489 \times 3}{2}$ = ·07335 ohm. The rail drop is therefore ·07335 × 40 = 2·934 volts. In this simple case the trolley wires are sufficient without feeder cables to carry the required current

without any undue drop. The drop in the rails is also within the 7-volt limit set by the Board of Trade.

79. If two cars are added to the line at the end of each mile, the first two taking 25 amperes each, and the second two 20 amperes each, the route will be as shown in Fig. 50, where *a* is the power station and *b c* the route, divided into mile lengths at *d* and *e*. The cars are shown at *f*. The voltage drop in the trolley wire between the end of the route and the first two cars,

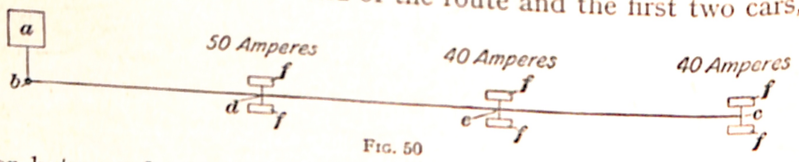


FIG. 50

or between *b* and *d*, is the current due to six cars multiplied by the resistance of the wires between *b* and *d*; or $[(4 \times 20) + (2 \times 25)] \times \frac{\cdot 3961}{2} = 25{\cdot}75$ volts, approximately. Between the first two and second two cars, or between *d* and *e*, the voltage drop is the current due to four cars multiplied by the resistance of the wires between *d* and *e*; or $4 \times 20 \times \frac{\cdot 3961}{2} = 15{\cdot}84$ volts, approximately. Between the second two and third two cars, or between *e* and *c*, the voltage drop is the product of the current due to two cars and the resistance of the wires between *e* and *c*; or $2 \times 20 \times \frac{\cdot 3961}{2} = 7{\cdot}92$ volts, approximately. The total drop, in volts, in the trolley wire is therefore $25{\cdot}75 + 15{\cdot}84 + 7{\cdot}92 = 49{\cdot}51$ volts, approximately.

The drop, in volts, in the rails between *b* and *d* is $130 \times \frac{\cdot 0489}{2} = 3{\cdot}18$ volts, approximately; between *d* and *e* the drop is $80 \times \frac{\cdot 0489}{2} = 1{\cdot}96$ volts, approximately; between *e* and *f* the drop is $40 \times \frac{\cdot 0489}{2} = \cdot 98$ volt, approximately; making a total drop in the rails of 6·12 volts, approximately. Since the drop in the trolley wire is 49·51 volts and the drop in the rails

6·12 volts, this is about the limit which would be used without extra feeder cables.

80. If the service just described is doubled, the drop in the line will be about 99 volts, and the drop in the rails about 12 volts. Some alteration must therefore be made in the feeding arrangements to reduce these figures. In such a case, it is advisable to divide the line electrically into two portions, each fed from a separate feeder, so as to localize any trouble arising from defective cars or other faults. This arrangement is shown in Fig. 51, in which *a* is the power station which supplies

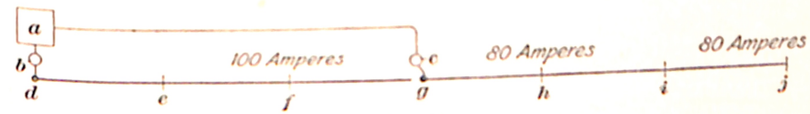


FIG. 51

current to the trolley wires through feeder pillars *b* and *c*. The 3-mile line *d j* is divided at *e*, *f*, *g*, *h*, and *i* into ½-mile sections by section insulators. The switch pillar at *b* is connected by a short feeder to the power station, and this feeder controls the three ½-mile sections from *d* to *g*. A feeder taken to feeder pillar *c* controls the three sections from *g* to *j*.

81. The voltage drop in the overhead line *g j* fed by the feeder is the drop in *g h* plus the drop in *h j*; or $(2 \times 80 \times \frac{\cdot 3961}{2} \times \frac{1}{2}) + (80 \times \frac{\cdot 3961}{2} \times 1) = 15{\cdot}84 + 15{\cdot}84 = 31{\cdot}68$ volts. If the lowest voltage on the trolley wire is to be 495 volts, and the pressure at the power station is 550 volts, the total permissible drop is $550 - 495 = 55$ volts. The drop in the trolley wire is 31·68 volts, so that the drop in feeder *a c* must be $55 - 31{\cdot}68 = 23{\cdot}32$ volts. The length of the feeder is 1½ miles, and the drop 23·32 volts; the drop per mile is therefore $\frac{23{\cdot}32 \times 2}{3} = 15{\cdot}54$ volts, approximately. The current to be carried by the feeder is 160 amperes, and from the curve given in Fig. 49, the nearest section of cable is ·45 square inch. The drop in the section *d g* is made up of the drop in *d f* plus the drop in *f g*. As the drop in *f g* is zero, the drop in *d g* equals

the drop in $d\,f$; or, $100 \times \frac{\cdot 3961}{2} \times 1 = 19{\cdot}80$ volts, approximately.

In order to reduce the drop on the rails, either return cables must be laid or a return cable laid in conjunction with a negative booster.

82. Effect of Distributed Load.—So far, the feeder problems have been worked out on the assumption that the load was bunched at one end. This is a condition that sometimes arises in practice, but it can hardly be looked on as the ordinary operating condition. In most cases, a number of cars are spaced at fairly regular intervals along the line, each car moving at an approximately uniform rate, with the result that current is taken off at a number of points that are continually shifting. The load

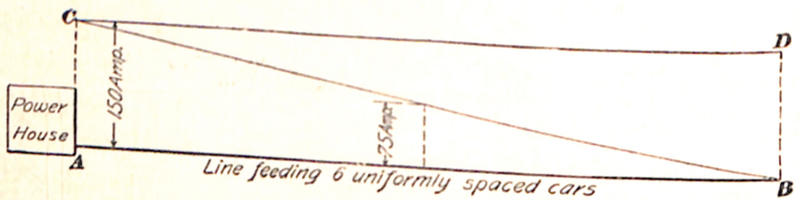


Fig. 52

is nearly uniformly distributed and there is a gradual falling off in current from the station to the end of the line. For example, suppose that $A\,B$, Fig. 52, represents a stretch of line that supplies six uniformly spaced cars moving at a uniform speed and taking 25 amperes per car. On account of the uniform movement and even spacing, the current will decrease gradually from 150 amperes at the station to zero at the end B. The falling off in the current may be represented by the line $C\,B$. The drop between A and B will therefore be found by multiplying the average current in $A\,B$ by the resistance. The average current is evidently one-half the station current, or 75 amperes; hence, if the resistance of $A\,B$ is $\frac{1}{2}$ ohm, the drop between A and B will be 37·5 volts.

83. If the whole load is bunched at B, Fig. 52, the current will be 150 amperes throughout the whole length, as represented

by the line $C\,D$, and the average current throughout the length will be the same as the current at the station, so that the drop will be $150 \times \frac{1}{2} = 75$ volts. Hence, for a given line wire and a given amount of current transmitted, the drop with a uniformly distributed load is one-half that with a concentrated end load. In other words, if calculations are made relating to a distributed load and the whole length of line is considered in the calculations, the current must be taken as one-half the actual current supplied to all the cars, because it falls off from the station, or feeding point, to the end of the line. Another, and perhaps a better, way of considering a distributed load is to look on it as if the whole

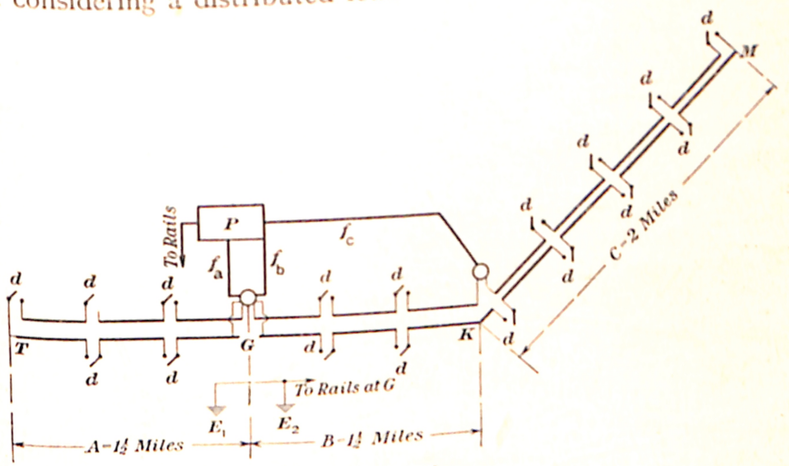


Fig. 53

load were concentrated at the middle of the line and work out the problem as if the whole current were transmitted over half the line.

84. Calculation of Feeders for Given Section.—In Fig. 53 is shown a system, with a power station at P, which is divided into two sections A, B, $1\frac{1}{2}$ miles long, and one section C, 2 miles long. The entire line is also divided into $\frac{1}{2}$-mile sections by insulators d. The rails weigh 95 pounds per yard and the trolley wire is No. 000 S.W.G. Sections A and B are double-track and have eight cars to the mile; the outlying section C is single-track and has four cars to the mile, half of the cars returning at K.

Since there are twelve cars, each requiring 20 amperes, in section A, considering the load as being concentrated at the centre, the drop in the trolley wire of this section is $12 \times 20 \times \frac{\cdot 3961}{2} \times \frac{3}{4} = 35{\cdot}65$ volts, approximately. Table IX gives the resistance per mile of a 95-pound rail as ·0463 ohm; therefore, the voltage drop in the rails in section A, in which the four rails are in parallel, is $240 \times \frac{\cdot 0463}{4} \times \frac{3}{4} = 2{\cdot}08$ volts, approximately.

85. If it is decided to feed this section by means of a short feeder f_a run to the point G, the additional drop in the feeder must be allowed for. This cable will be $\frac{1}{2}$ mile in length, and if 14·35-volts drop is allowed in it, a maximum of 50-volts positive drop at the farthest point of the line will be obtained. The drop per mile in the cable is therefore $14{\cdot}35 \times 2 = 28{\cdot}7$, and the current to be carried is 240 amperes. From the curve shown in Fig. 49, the nearest larger section of cable is found to be ·4 square inch. Section B, Fig. 53, is exactly the same as section A, so that a second ·4-inch cable f_b will be run to G, the drop in the trolley wire being 35·65 volts, and the drop in the rails 2·08 volts.

In the present instance there is a drop of about 15 volts in the cable and a drop in the line of about 35 volts, but it would be equally good electrically to allow a larger drop in the cable and a smaller drop in the line, so long as the total drop remains the same. A larger drop in the cable will mean that a smaller cable may be used, but an additional distributing cable would be required from G, Fig. 53, to the first section insulator to reduce the drop in the line. The greatest care must be taken to fix as the minimum size a cable which will carry the current safely; in the present instance, a cable less than ·25 square inch in area would not be used.

86. In the outlying section C, Fig. 53, which extends from K to M, the voltage drop in the trolley wires is the product of the current and the resistance of one-half the route length of line. As there are four cars per mile, or eight cars, on this section, and

as these take 20 amperes each, the drop is $160 \times \frac{\cdot 3961}{2} \times 1 = 31{\cdot}69$ volts, approximately. The voltage drop in the rails is $160 \times \frac{\cdot 0463}{2} \times 1 = 3{\cdot}7$ volts. The length of feeder f_c required to connect one end K of the section C to the station is 2 miles; therefore, the greatest drop permissible in it is $50 - 31{\cdot}69 = 18{\cdot}31$ volts. The drop per mile in the cable is thus $\frac{18{\cdot}31}{2} = 9{\cdot}15$ volts, approximately, and the current is 160 amperes. From the curve shown in Fig. 49, the section of cable required is ·8 square inch.

This section is, however, much too large, considering the current which it will have to carry, as a much smaller cable will carry 160 amperes safely. It is therefore necessary to consider whether there is a more economical method of dealing with this section. If a ·35-square inch cable is used, the drop in it will be 40 volts, so that the line drop must be only 10 volts instead of 31·69. To reduce the line drop to 10 volts will require along the route a heavy distributing cable, which will have to carry about two-thirds of the current. Its resistance must therefore be one-half that of the trolley wires, or ·099 ohm; a cable about ·45 square inch is therefore needed. It is thus clear that 2 miles of ·35-inch cable and 2 miles of ·45-inch cable are required. This means that the weight of copper required is the same as before, because the combined sections of the cables are the same, that is, $\cdot 35 + \cdot 45 = \cdot 8$.

87. Another method which could be adopted is to install a positive booster in conjunction with the ·35-inch feeder from the power house P to the end K. This booster would supply the difference between 40 volts and 18·31 volts, or 21·69 volts. As the current passing is 160 amperes, the output of the booster must be $21{\cdot}69 \times 160 = 3{,}470$ watts $= 3{\cdot}5$ kilowatts, nearly. Any of these methods could be successfully adopted. The most economical method may be found by applying Kelvin's law, making the cost of the watts lost in transmission equal to the interest on the capital cost plus the allowance for depreciation.

88. As regards the return, the drop in the rails from T to G is 2·08 volts, and the drop from M to G is 2·08 + 3·7 = 5·78 volts, both of which values are within the Board of Trade limit. The earth plates are placed at G, and the negative feeders connected between the rails at G and the power-station bus-bars. The total current returning on these cables is 240 + 240 + 160 = 640 amperes, so that the minimum size which may be used, as shown in Fig. 49, must have a sectional area of about ·9 square inch. If this section is adopted, the drop, in volts, per mile, from Fig. 49, will be 31·2. As the feeder is $\frac{1}{2}$ mile long, the voltage drop in it will be $\frac{31{\cdot}2}{2} = 15{\cdot}6$. The total drop in section A, Fig. 53, will therefore be 35·65 + 2·08 + 14·35 + 15·6 = 67·68 volts. In section B, the drop will also be 67·68 volts. In section C, it will be 31·69 + 3·7 + 18·31 + 15·6 = 69·3 volts. By operating the power-station generators at 570 volts at full load, a minimum pressure of 500 volts at the farthest point of the line may be obtained. At the nearest point to the station, the line voltage will be the station voltage less the drop in the feeders between the station and G, or 570 − (14·35 + 15·6) = 540 volts, approximately. The Board of Trade test wires will be run to the points T, K, and M.

ACCIDENTS DUE TO FALLEN TROLLEY WIRES

METHODS OF DEALING WITH FALLEN WIRES

89. **General Instructions.**—Should a trolley wire or its suspension break, or a telegraph or telephone wire fall and come in contact with a trolley wire, the fallen wires should not be interfered with unless it is necessary to do so to prevent injury or to save life. The current should at once be cut off from the section by means of the switches in the feeder pillars, and notification of the accident sent to the power station. Many feeder pillars are in telephonic communication with the power station, so that help can be summoned when the current is cut off. If a wire, as it lies in the street, is an obstruction to traffic, it may

be pulled on one side by means of a stick, such as a walking stick with a hooked handle, or it may be moved by a person wearing india-rubber gloves. As the wire, especially if thin, may be hot, the rubber gloves should be protected by using a silk scarf, cloth cap, or similar article, in addition.

90. If the fallen wire is in contact with anyone, and it is necessary to remove it at once to save life or prevent injury, the following precautions must be observed:

1. Never touch the trolley wire, nor any person or metallic substance in contact with it, with bare hands or damp gloves.
2. The wire or the person in contact with it may be safely handled by using india-rubber gloves, dry clothing, dry rope, or a dry stick. It is most important that the article used should be dry, as damp material will act as a conductor. A dry india-rubber mat, such as is often used in cabs, carriages, or at shop doors, forms an excellent insulator, and a person standing on such a mat can handle the trolley wire freely, though it is best not to use the bare hands. A dry mackintosh is an excellent material to use when handling the trolley wire.
3. If it is not possible to get the person out of contact with the trolley wire, or to cut off the current at once, the fallen wire may be forced into contact with the tramway rails by the use of a dry wooden pole or a large piece of dry wood. This will result in a short-circuit, accompanied by a very violent flash; the fallen wire should, however, be held firmly in contact with the rails, and the person in contact with the wire released. If cutting appliances with insulated handles are available, the trolley wire may be cut at a point between the victim and the overhead portion of the wire.

APPARENT DEATH FROM ELECTRIC SHOCK

91. **Application of Artificial Respiration.**—In cases of apparent death from electric shock, restorative measures should be started without a moment's delay when the patient has been removed from contact with the live conductor, and a doctor should be sent for at once. The first step is to apply **artificial respiration,** and this should be persevered in for several hours. When

artificial respiration is applied, the chest is first made to expand, thus enlarging its cavity and causing the air to be sucked in, just as a pair of bellows fills with air when opened. Then the chest is made to contract, so that its capacity for holding air is reduced, and the air is thus forced out. When these movements are performed alternately, there is first inspiration, then expiration, and the two together constitute respiration, or breathing.

92. Method for Three Operators.—To produce artificial respiration, place the patient on his back, with the back just below the shoulders resting on a roll of clothing, so that the pit of the stomach is just above the level of the rest of the body. Next, the teeth must be gently but firmly forced apart, using a piece

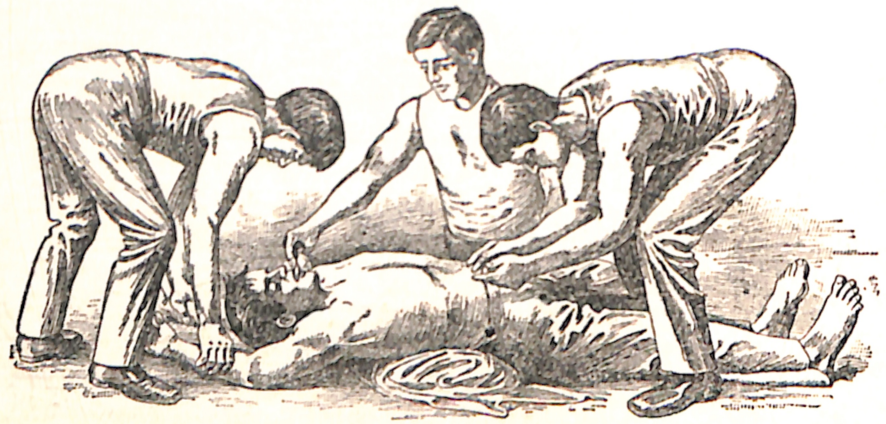


FIG. 54

of wood or the handle of a pocket-knife if necessary, and the tip of the tongue must be drawn forwards and out of the mouth, as otherwise it will fall back into the throat and impede the breathing. This is an important matter, for if it is not done successfully, all that would otherwise be gained by artificial respiration may not be accomplished. An assistant should grasp the tongue with a dry handkerchief, or other cloth, to prevent its slipping from the fingers ; or he may cover his fingers with sand for the same purpose, kneeling meanwhile at the side of the patient, as shown in Fig. 54, and holding the tongue out in such a manner as not to let his hand and arm interfere with the movements now to be described.

93. After the position of the tongue has been adjusted, another assistant should kneel or stand behind the patient's head, grasp him by the forearms half-way between the elbows and wrists, and draw the arms up over the patient's head by moving them in a vertical plane rather quickly, but steadily, until the hands touch the ground or floor behind the head, as shown in Fig. 54, holding them there for 2 seconds. This motion draws up the ribs, expanding the chest so that air enters; the arms being held thus for 2 seconds allows sufficient time for the air to completely fill the lungs. Now reverse the first movement, that is, carry the arms back until they are parallel to and near the sides of the chest, as shown in Fig. 55, the assistant who



FIG. 55

is holding the tongue changing hands, if necessary, to let the arms pass. Press the forearms firmly downwards for 1 second. This pressure depresses the ribs, contracts the chest, and forces out the air.

94. While this is being done, let a third assistant take a position astride the patient's hips, with his elbows resting on his own knees and his hands extended ready for action. Just before the patient's hands reach the ground, the man astride the body should grasp the body with his hands, the balls of the thumbs resting on either side of the pit of the stomach, the fingers falling into the grooves between the short ribs. Now, using his knees as a pivot, he should, at the moment the patient's hands touch

the ground, throw, not too suddenly, all his weight forwards on his hands, and at the same time squeeze the waist between them, as if he wished to force something in the chest upwards out of the mouth. He should increase the pressure while he slowly counts one, two, three, four (about 2 seconds), and then suddenly let go with a final push, which will throw him back to his first position. This completes expiration.

95. At the moment the pressure is taken from the waist, the man at the patient's head will again steadily draw the arms upwards to the sides of the patient's head (the assistant holding the tongue again changing hands to let the arms pass, if necessary), holding them there while he slowly counts one, two, three, four (about 2 seconds). These movements should be repeated alternately, regularly, and persistently, and at the rate of sixteen times per minute, until some effort is made by the patient to breathe. This effort may be only a gasp. Wait a moment to see if the patient will breathe again ; if not, again perform artificial respiration, but now endeavour to time the movements by the efforts to breathe, and at the same time resort to hartshorn or smelling-salts, dashing cold water in the face, and slapping and rubbing the surface of the body, until gradually respiration is established. If the patient does not show signs of breathing, do not give up or lose confidence. It is a fallacy to suppose that persons are irrecoverable because life does not soon make its reappearance ; persons have been restored after many hours' work.

96. Immediately after a spontaneous effort to breathe is perceived, stop imitating the movements of breathing, and proceed to induce circulation and warmth. After respiration has been restored, be careful to let the air circulate freely about the patient. On the restoration of breathing, a teaspoonful of warm water should be given ; and then, if the power of swallowing has returned, follow by small quantities of wine, warm brandy and water, or coffee. The patient should be kept in bed, and a disposition to sleep encouraged. If there is pain or difficulty in breathing, apply a hot linseed poultice over the chest. Watch the patient closely for some time, lest the breathing should fail ;

should any signs of failure appear, at once recommence artificial respiration.

97. Method for One Operator.—To produce respiration artificially, if no assistance is at hand and one person must work



Fig. 56

alone, place the patient on his back with the shoulders slightly raised on a folded article of clothing ; draw forwards the tongue and keep it projecting just beyond the lips by tying it between the teeth, as shown in Figs. 56 and 57, or, better still, with an



Fig. 57

elastic band, if there is one at hand, slipped under the chin. Grasp the arms just below the elbows and steadily draw them upwards in a vertical plane by the sides of the patient's head, allowing the hands to nearly meet, as shown in Fig. 56. Next, swing the arms down to the sides and press firmly downwards

and inwards on the sides and front of the chest over the lower ribs, drawing toward the patient's head, as shown in Fig. 57. Repeat these movements 12 to 15 times every minute.

98. Precautions. — In any operation for restoring respiration, remember the following precautions: Prevent unnecessary crowding of persons round the patient, especially if in a room. Avoid rough usage. Do not allow the patient to remain on his back, unless the tongue is secured. On no account place the patient in a warm bath, unless under medical direction, and even then this expedient should be employed only as a momentary excitant. Always place a wedge of hard rubber or wood between the patient's teeth, as returning animation is usually accompanied by a spasmodic closing of the jaws which is liable to injure, if not to sever, the patient's tongue, since it is being held forward either by the teeth or by another operator, who might not release it quickly enough. When the operator is alone, the tongue should not be held directly by the teeth; it should be placed between the folds of a piece of cloth or paper so arranged as not to impede breathing.