in the generating station and cut the current off the trolley wire. Seven-stranded steel cable of 16 gauge is more satisfactory for the purpose of guard wires than the equivalent single wire of No. 8 S.W.G.

Where guard wires are used, their additional weight and consequent stress must be taken into consideration in determining the size and location of poles. Where wires cross curves or junctions it is practically impossible to erect efficient protective devices, and arrangement should be made with the owners of these wires to deflect them at such points.

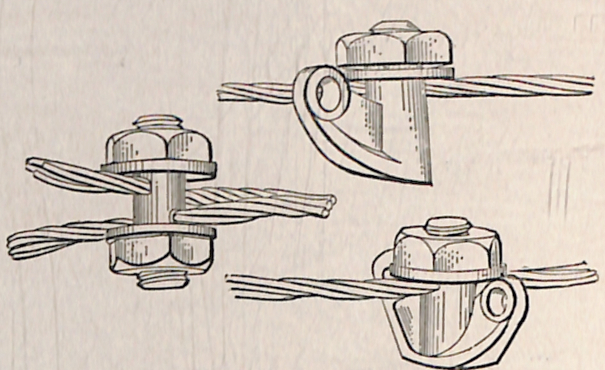


Fig. 160.—Guard-wire Clips

The attitude of the authorities towards tramways on the guard-wire question is somewhat unfair. They compel the tramway to afford protection against defective workmanship or maintenance on the part of the owners of the telephone or other telegraph wires, not only in regard to wires in position before the tramways were built, but any additional wires that may be erected. Guard wires are very unsightly, a considerable expense, and a source of danger to the tramway, as, in event of the trolley leaving the wire, it is very liable to get caught in the guard wires and pull them down. The actual amount of protection afforded is in most instances very slight. This refers particularly to long spans, and spans crossing the trolley lines at a sharp angle. Co-operation between the respective owners of the wires would enable a much more efficient protection to be given, with much less disfigurement. But this co-operation is difficult to arrive at, as the owners of the wires usually adopt an impossible attitude, saying, in effect: The Board of Trade regulations throw the whole responsibility on you; why should we trouble ourselves in the matter?

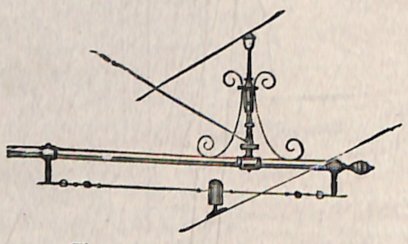


Fig. 161.—Guard-wire Standard

Full details as to the statutory requirements of the British Board of Trade and British Post Office will be obtained from the Regulations and Explanatory Memoranda issued by these authorities. Care should be taken to have the latest issued regulations, as those of an earlier date are generally superseded by newer publications.

CHAPTER VII

THE OPEN-CONDUIT SYSTEM

Introduction.—Conduit systems of electric traction are those in which the moving cars are supplied with current from conductors fixed in a conduit or tube below the track, by means of a current collector or plough carried by the car, and passing through and along a continuous slot in the surface of the roadway.

They may be divided in two ways:—

Open and closed conduits.
Shallow and deep conduits.

The great difficulty with which conduit systems have to contend is that due to the entrance of mud, water, dirt, &c., into and through the slot from the surface of the roadway.

Open and Closed Conduits.—The idea of the closed conduit was to get over this difficulty by the use of some mechanical arrangement by means of which the slot opening was under ordinary circumstances closed, thereby preventing foreign matter from entering the conduit; the arrangement being such that the plough could force aside the closing mechanism, which shut again after the car had passed. Several arrangements were worked out on this principle, but they all appear to have failed owing to dirt forcing its way in and preventing the proper operation of the closing or opening mechanism. One form of the Bentley-Knight system was constructed with the slot rails supported at the outer lower edges and free to fall together, thereby closing the slot. Dirt, however, worked in behind these slot rails and prevented their free movement. The arrangement is shown in fig. 162. All the conduits which have survived are *open* conduits.

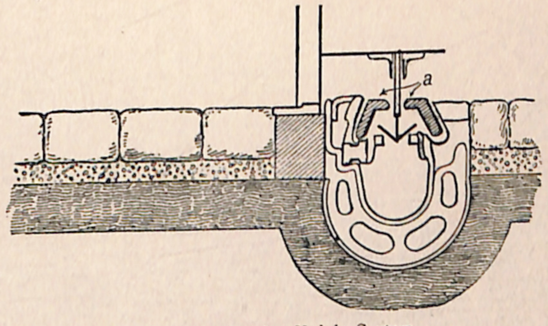


Fig. 162.—Bentley-Knight System

a, Slot-closing rails.

Deep and Shallow Conduits.—The closed conduit was in reality an attempt to render feasible the operation of the shallow conduit, which, as its name implies, was a channel of small depth, the object being to avoid the more or less considerable excavation required by the deeper forms of conduit. The liability of the conduit becoming choked with debris, and thereby preventing the operation of the particular system, has also prevented their being successful.

Many shallow conduits have been devised, some of which are interesting. One such system consisted of a plough of a length somewhat less than that of the car, and constructed so as to be to a certain extent flexible. This collector was supported at two or more points from the car truck, and was so arranged that, as it was carried along the conduit with the passage of the car, it forced its way between projecting contacts placed at regular intervals. These contact-pieces made contact with the positive and negative collecting-surfaces on each side of the plough, and, being at the same time pressed outwards by its passage, made contact at the other end with an insulated cable by means of a type of bayonet-switch. When the car had passed, these contact-pieces were forced outwards by spring action, and thereby became disconnected from the circuit. The switch-gear was contained in watertight boxes, and the whole depth of the conduit was not more than that of the tramway rails. A similar type of shallow conduit is also employed with the Kingsland surface-contact system for operating the stud switches. In this case, however, pits are provided at intervals of about

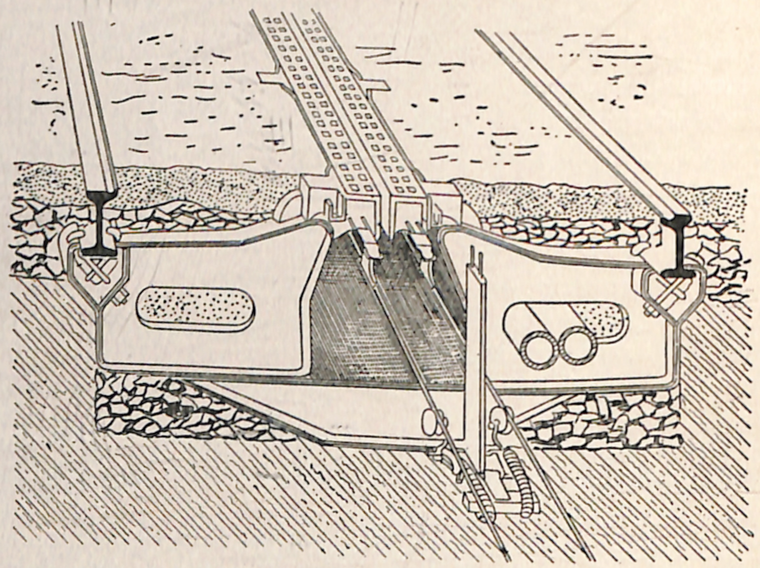


Fig. 163.—Love Conduit

every 15 to 20 feet, into which, it is claimed, all debris entering through the slot will be carried by the action of the strikers on the car.

Open and Deep Conduits.—The introduction of conduit systems was due to the objection made in some places to the adoption of the overhead trolley system, principally on æsthetic grounds. One of the first ideas was to make an arrangement in which the overhead trolley wire, instead of being placed above the track, should be placed underground, in a conduit, and reached through an opening in the surface of the roadway. The earlier structures were distinguished by being, as a rule, shallow, and with wide slots frequently so constructed that the conduit could be opened up for the purposes of cleaning by removing the detachable covers forming the road surface. These points are illustrated respectively very strongly in the Love conduit system, which was put down in Washington, and the arrangement of removable conduit covers adopted in Dresden and Blackpool.

The Love Conduit System.—The Love conduit system, after being exhibited at Chicago, was installed on a length of about 1¼ miles of track in Washington, and was probably the oldest line in America working on

a conduit system, and was in more or less successful operation up to 1900, after which the construction was modified in accordance with modern practice.

Fig. 163 shows a section of the Love conduit. Two conductors were employed, consisting of copper wires carried on insulators supported from the yokes; contact was made with these by means of a bar carried below the car passing through a slot in the surface of the roadway, and carrying at its lower end a double trolley with trolley wheels pressing against the under side of the above-mentioned conductors.

The system was ultimately replaced, owing to difficulties introduced by the expansion of the conductors causing them to deviate from the straight, thereby producing frequent short circuits and tendency for the trolleys to jump the conductors.

Dresden.—The conduit in Dresden was fixed under one of the running rails, and was made accessible over its entire length by means of cast-iron plates forming one side of the slot. Owing to these plates having a certain amount of lateral play the slot was wide and somewhat irregular, varying between 1 and 2 inches. Fig. 164 shows a section of the track and the removable covers to the conduit.

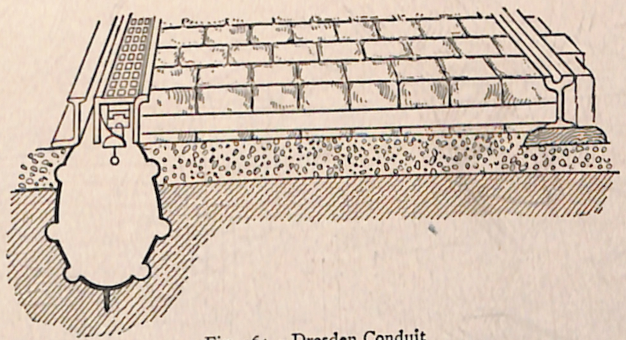


Fig. 164.—Dresden Conduit

Blackpool.—Fig. 165 shows a section of the Blackpool conduit. This was also accessible over its whole length, but, having in most places two conductors, has a cover on each side of the slot.

Although undoubtedly the Holroyd-Smith conduit had various defects —and it must not be forgotten that the line in Blackpool was laid down in 1884—its ultimate removal from Blackpool was due not so much to these as to the fact that any conduit system would have proved unworkable in its position, the line being at times flooded with sea-water heavily-laden with sand, completely choking the conduit. No system of drainage could prove effective in such a case.

Conduit lines have been constructed in various places on the Continent and in America, including Budapest, Dresden, Paris, Berlin, Brussels, Lyons, Washington, New York, Chicago, and Baltimore. Before, however, going into details of these systems it may be well to consider the general lines on which the modern conduit has been developed and the conditions which it is required to fulfil.

Owing to the determined and continued opposition of certain American cities—notably New York and Washington—to the use in their streets of the overhead system the American street car companies were obliged to seek some other method of operating their systems and avoiding these objections. The American companies already knew what could be done with a frequent service of rapid cars owing to their experience with the cable system. The heavy cost of maintenance, however, made them anxious to try some other alternative. They were not afraid, therefore, of incurring considerable capital outlay.

The first section of electric conduit in New York was built entirely as an experiment, and the design of the conduit was so chosen that, should the electrical arrangement prove unsatisfactory, the line could be converted to cable traction at comparatively small cost. It may be added, however, that the engineers in charge of the design and construction of this work

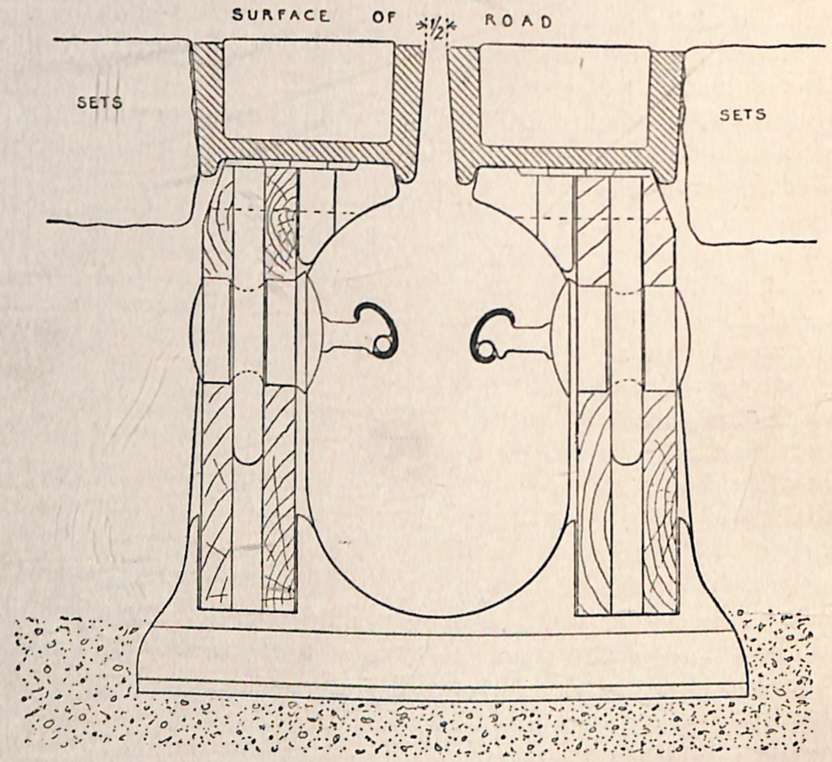


Fig. 165.—Transverse Section of Conduit, Blackpool Electric Railway

did not anticipate any necessity for the adoption of this course. The experiment proved entirely successful, the lines since constructed have been laid down on a similar design, and there are now at work some 20 miles of conduit system in New York alone. It may thus be seen that the modern conduit is a direct outcome of the experience gained with the cable system. It has been developed chiefly by the General Electric Company in America, and by the affiliations of this company and Messrs. Siemens & Halske on the Continent.

Advantages and Disadvantages of the Conduit System. — The great claims made on behalf of the open-slot conduit system as designed to-day are:—

1. That, the electrical conductors being entirely underground and out of reach, absolute safety is secured to the public.

2. That the working of the regular service on this system is as free from interruption as with any other system of mechanical operation.

3. That there are no overhead wires, poles, or other obstructions in the roadway.

The great drawbacks to the system are its great initial capital cost, the increased cost of operation due to the expense incurred in maintaining and cleaning the conduit, and existence of the slot in the roadway usually with its attendant extra pair of slot rails. In this latter connection, however, it is pointed out that with a slot not exceeding $\frac{5}{8}$ to $\frac{3}{4}$ inch, and with narrow slot rails, or still more so where the conduit is constructed under one of the running rails, this latter objection is of small weight. Slots of $1\frac{1}{4}$ inches and over, and constructions which are apt to be specially wide at points, such as may be found in some places on the Continent, would never, however, be tolerated in this country.

In designing a conduit system a number of points have to be taken into consideration, most of which vary according to local conditions.

Climate.—The question of climate is not of paramount importance, as in this respect the conduit system is at no greater disadvantage than other systems of traction, with perhaps the exception of very heavy rainfall. Suitable provision must be provided for draining the conduit, sufficiently ample to deal with the heaviest rainfall likely to occur, due consideration being given to the gradients, so as to avoid the likelihood of water accumulating at certain points of the route. Cases have occurred, however, in which, in spite of exceptional rainfall, the car service has been maintained through short, flooded sections of conduit without greater difficulty than that of providing the extra leakage current consumed. This has occurred on two or three occasions in Washington, while, on the other hand, serious interruptions have been occasioned by the same cause in Vienna. The difference in the two cases has probably been brought about by the extent of the track flooded in one case being much greater than in the other, the leakage of current under these conditions being very considerable.

State of the Roadway and Cleaning.—It is perfectly clear that provision has to be made for the periodical removal of all extraneous matter finding its way through the slot into the conduit.

According to local conditions it will be found necessary to place the cleaning-pits closer together in some places than in others, and this depends to a certain extent on climate.

The method of cleaning adopted by different companies operating with conduit system appears to vary considerably. The system yielding the best results appears to be that in which the conduit is cleared at regular and frequent intervals. In New York the conduit is cleared *daily* by means of a scraper attached to a horse wagon. The result is that the actual amount of matter to be removed is very small, and there is no possibility of any accumulation forming in the conduit.

In Brussels, where there are about $14\frac{1}{2}$ miles of double track on the conduit system, the cleaning of the slot and conduit is done by a gang of about ten men, who go systematically over the whole system about once every seven days. There is little doubt, however, that the daily system of cleaning adopted in New York is the more satisfactory method, and accounts for the excellent state in which the New York conduit is maintained. The cost of cleaning in New York is given as 0.055 of a penny per car mile.

Type of Paving.—The type of paving with which a conduit track is paved is important, because on account of other traffic it is desirable, there being possibly three sets of rails instead of two, that a good even surface is maintained, and so laid that it tends to throw rain-water, &c., away from the slot; and, secondly, on account of the necessity, particularly in this country, where the width of the slot is limited, of maintaining the slot at the right gauge.

On account of the high capital cost of tramways constructed on the conduit system it is unlikely to be used, except in the central areas of large towns or where for other reasons the overhead construction is inadmissible. In such positions the paving already in existence will generally be either asphalt, wood (either creosoted or Australian timber), or some form of granite sett, and will extend not just over the width of the track but over the whole width of the roadway.

Granite and asphalt paving present no special difficulty, but in the case of wood paving precaution has to be taken to construct the conduit of ample strength to resist the expansion of the wood when thoroughly soaked with water, as otherwise the closing up of the slot will result.

With wood paving as usually laid, a space of from ½ to 1½ inches, according to the width of the roadway, is left clear on each side between the paving and the curb in order to allow for this expansion. This allowance, however, is frequently insufficient, as is shown by the forcing of the curb-stones out of position, which sometimes takes place. It is by no means easy to arrive at a correct estimate of the pressure which wood-paving is capable of exerting in this manner. It is, however, undoubtedly considerable, and from some rough experiments has been estimated at about 2½ tons per lineal metre. Where wood paving is in use the general practice is now to lay the space between the tracks with well-faced granite setts.

Construction.—In considering the design of conduit and its equipment, alternate methods of construction suggest themselves. They may be discussed under the headings of—

Central *v.* Side Slot,
Rigid *v.* Flexible Conductors, and also
Single *v.* Double Insulated Conductors.

It will probably simplify matters to discuss the electrical considerations involved first. In this respect there are two possible arrangements, namely:—

1. That in which both positive and negative conductors are insulated and placed in the conduit, and
2. That in which the track rails are employed for the return circuit.

Most of the earlier conduits belong to this latter class, including the systems laid down in Blackpool, Dresden, Budapest, as also in the Waller-Manville or Simplex system. That these systems have not received further extension has been due not so much to an inferiority in the single-conductor design as to defects in other more important details.

The difference is an important one. Where the return circuit is by the track rails, the conduit contains conductors of one polarity only, and the whole attention of the designer can be devoted to making the insulation of the unipolar conductor or conductors as perfect as possible. The difficult problem of designing the conductor arrangements at crossings and turn-outs is hereby also very much simplified.

From an electrical point of view the problem resolves itself into two questions: of insulation and continuity of supply. Mechanically it affects most of the details of construction, which will be dealt with as they arise. The question of continuity arises only at points and crossings. Where both poles are insulated, and conductors of each polarity are fixed in the conduit, it is obvious that at crossings and points the conductor bars have to be interrupted. The interruption is, of course, smallest at crossings, but may amount at points and special work to lengths of 12 feet and over. In order to meet this difficulty it is necessary either to equip the car with two collecting-ploughs placed sufficiently far apart to enable them to bridge any gap in the conduit conductors which may occur, or the car has to travel through such gaps by its own momentum; and should by any chance a car be stopped in such a position, external force has to be applied to set it in motion. This, however, with good management, is seldom likely to occur, and the principal drawback is the extinction of the car lighting which occurs at such spots at night-time. Where, on the other hand, conductors of only one polarity are used in the conduit, such interruptions of the conductors at crossings are not absolutely necessary, and at points, by the employment of two conductors, one on each side of the plough, the supply is continuous whichever branch the car takes.

Rigid v. Flexible Conductors.—It may be well here to consider for a moment the question of rigid and flexible conductors. Flexible conductors are continuous, rigid conductors jointed. As mentioned above, one of the first ideas in the construction of a conduit system was to build an underground trolley system. The Love system was designed on this principle, and was a double-conductor system. The difficulty with flexible conductors arises from the fact that increase of temperature produces an expansion of the conductor. The conductor not being rigid, such expansion will produce a sagging unless mechanism is provided for taking up such expansion as occurs. In the Love system a spring mechanism was provided, but owing to the method of fixing the conductors to the insulators, and the support of the latter, only a comparatively limited play was allowed, and it was also found that the continued passage of the cars caused a motion of the conductor in one direction. The result of this movement was that a limit of play was reached, and the spring arrangement was unable to maintain the conductor at all in a stretched condition. Sagging was produced, which ultimately led to short circuit or a jumping of the trolleys from the trolley wire.

Another system employing a flexible conductor is the Waller-Manville or Simplex system. In this system in its usual form only one conductor is employed. This conductor is not rigidly attached in any way to the insulators, but rests on insulated projecting arms from which it is lifted by the collector-shoe on the car. It is therefore free to move along its length. The conductor is kept in a stretched condition, and all expansion due to temperature variation taken up by means of a powerful straining device consisting of a weight attached direct to the trolley wire. By this means any sagging of the conductor beyond that only natural between the points of support was removed, and the liability of a break-down from this cause thereby obviated. Owing to the collecting-shoe lifting the conductor off the insulators the latter are subjected to no strains as the car passes them. At curves it is, of course, necessary to provide some means

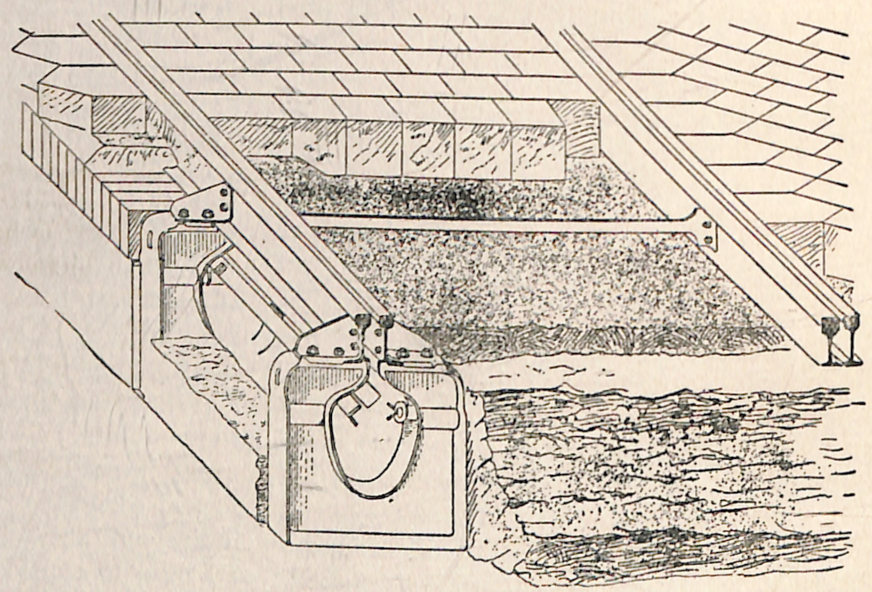


Fig. 166.—Conduit, Budapest

to prevent the conductor being drawn into the side of the conduit, and in such positions the arrangement is modified by the employment of insulated arms pivoted so as to allow a vertical movement of the conductor, which falls back into its normal position after the passage of the car. The insulators being placed closer together at curves, sagging due to expansion in the short lengths between them is inconsiderable and produces no difficulty.

The Budapest system was the first to make use of rigid conductors, and in all the modern lines laid down rigid conductors have been employed, fixed at the central insulating support, sufficient space being allowed at the ends to provide for the necessary expansion.

Insulation.—The design and arrangement of the insulators for a conduit system is a problem of no light difficulty. As practically all tramway work at the present time is worked at a pressure of from 500 to 600 volts, lower pressures, though they have been employed, may be left out of consideration. The adoption of the lower voltage might render the liability to break down less, but the question of insulating for the above pressures now presents no special difficulties. The adoption of even

higher pressures might be taken into consideration were it not for the fact that conduit-work lines are only as a rule part of a larger system, and that it would involve the departure from the standard car equipments now on the market, there being objections to the use of more than 500 volts with trolley lines.

As in the course of a longer or shorter time, depending on local conditions, the insulators will become covered with a coating of more or less conducting material, therefore, other things being equal, it is desirable to keep the number of insulators to a minimum. It is also necessary to provide some means of cleaning them.

Various methods have been adopted for the support of insulators employed—from the floor of the conduit, from the upper part of the yokes, the slot-rails, or especial fixing in the roof of the conduit. Further, they have been either entirely enclosed in the conduit or rendered accessible by means of surface-boxes in the roadway. The method of support from the floor of the conduit has not proved satisfactory, however, as the free passage along the lower portion of the conduit is obstructed thereby, and it is difficult to easily remove dirt and debris collecting round the foot of the support. The latter method, therefore, of supporting from the upper portion of the conduit, is that now generally adopted. The question as to whether it is necessary to provide access through the roadway to the insulators appears, however, to be a matter of opinion. As extra space is required in the conduit at the positions in which the insulators are fixed, a recess is formed, in which a certain amount of debris will collect. In New York, where the system of fixing a surface-box over each insulator is adopted, these openings are employed partly for cleaning the conduit, in addition to providing access to the insulators.

But these surface-boxes are not really necessary. A water-jet directed on the insulators by means of a specially-shaped nozzle inserted through the slot is quite sufficient, in all ordinary cases, to remove the dirt and foreign matter which may have collected on them, and the absence of the double surface-box at regular intervals along the whole length of the track very greatly improves the appearance of the roadway, particularly where the side slot is employed. The roof of the conduit over each insulator is formed by a steel plate, on which the paving rests. The necessity of replacing an insulator occurs only at rare intervals, and in such cases it is cheaper to remove the road paving for this purpose than to make each insulator accessible. On removal of the paving and steel plate the insulator may easily be got at.

In most systems it has been found possible to keep the number of insulators down to two for each length of conductor-rail. The weight of the conductors which the insulators have to carry may vary considerably; in addition, they have to withstand any side strains which may be communicated to them from the plough. Where the conductor-rail is interrupted the end is usually splayed off so as to allow an easy entrance of the plough-shoe, and, in order to better sustain the shock at such points, two insulators are usually employed. It is also essential that the conductor-rails should be fixed centrally with the slot, as otherwise destructive side pressures will be produced. The insulator supports are so designed as to make provision for the adjustment of this in erection.

The weight of conductor-rails may vary up to 25 lbs. per yard, the usual weight being from 18 to 22 lbs., and the design and construction of the insulators is probably one of the most important details in the successful and economical working of a conduit system. The leakage path should be as long as possible in order to secure high insulation, of such a shape as not to become coated with dirt, and at the same time be so designed as to secure the maximum of mechanical strength.

In connection with the subject of insulation, the question of the necessity or otherwise of insulating both conductors again arises. As mentioned above, certain advantages are obtained by insulating one pole only, and using track rails for return circuit.

About the time, however, when the later conduit lines were put down in America, other considerations had become important. Alarming accounts were circulated as to the damage to gas- and water-pipes which might be expected to occur from electrolysis, especially in the centres of large towns.

As the conduit system in America was a modification of cable tramway construction, it was argued that by insulating both conductors all the dangers of electrolysis would be avoided, and that as the principal cost in installing the system was that of constructing the conduit, the security so obtained would be well worth the extra comparatively small initial outlay It was also argued that, both conductors being insulated, very much greater drop of pressure could be allowed in the return circuit than would be the case where an earth return is adopted. It should, however, be borne in mind that with the heavy track rails now employed a circuit of great conductivity is provided, by the use of which the drop in the return can be reduced to a very small figure, and the saving in energy wasted may represent an appreciable figure in the year's working. Further, it may be taken as fairly proven that, by maintaining the drop in the earth returns within the limits prescribed by the Board of Trade, or, say, at an average not exceeding 4 volts, no bad results need be anticipated from electrolytic action.

The significant point, however, in the employment of two insulated conductors lies in the well-known fact that on exposed insulated surfaces a deposit tends to form which gradually reduces the insulation of the negative conductor and brings it to earth potential. The following are the results of some tests made in this connection on some of the lines in Washington.

A.—Insulation Resistance in Ohms

Circuit Number.	17th October.		15th November.		6th December.	
	Positive.	Negative.	Positive.	Negative.	Positive.	Negative.
1.	19,500	770	8300	400	36,800	1250
2.	16,500	280	5200	14	25,800	700
3.	18,100	670	8000	480	29,100	830
4.	10,900	770	5200	330	27,600	910

B.—Tests on Circuit No. 4

Date.	Resistance East Conductor.	Polarity.	Resistance West Conductor.	Polarity.	Remarks.
Dec. 6.	27,600 ohms.	+	910 ohms.	−	Reversed after test.
Dec. 24.	280 „	−	2500 „	+	
Jan. 9.	5,000 „	+	780 „	−	

Table A gives the insulation resistance in ohms of four separate circuits on three separate dates, from which it will be seen that the insulation of the positive conductor averages more than twenty times that of the negative, the negative insulation varying from about 70 to 300 ohms per mile.

Each of the four circuits consists of approximately 4 miles of conductors, each supported by, roughly, 1500 insulators.

The differences on the different dates are probably due to the state of the weather, 17th October being dry; 15th November hard rain; and 6th December dry and cold, with no rain during the previous week. The exceptionally low reading of the negative conductor of No. 2 circuit on 15th November was due to a local fault in a rubber connecting-cable at a crossing.

In order to ascertain whether this difference was due entirely to this question of polarity, the polarity of one of the circuits was reversed, the results being given in Table B.

The question therefore arises whether any real result is obtained by placing an insulated negative conductor in the conduit.

In actual working, however, earths are likely to and do occur from other causes, both in the insulation of the conductors and in the ploughs, and in order to meet the difficulties produced thereby it has been found necessary to divide conduit tramway networks into independent sections. Special arrangements are made at the switch-board so that the polarity of the feeders, which are connected to and supply these sections, may be reversed at any time. In order to keep the insulation of both conductors in a uniform state of efficiency, it is usual to reverse the polarity at regular intervals, usually about once every three or four weeks. This device makes it possible at any time to connect a conductor of which the insulation is faulty to the negative pole, and in the event of either pole in a plough or car equipment going to earth, to keep the polarity of the conductors of the section on which the car is placed so that the fault on the car or plough is kept on the negative side of the system, thereby avoiding a short circuit. (It is clear, of course, that this cannot be done if a faulty car earths the insulated side of a faulty section of line.) The whole argument in favour of double-insulated, and the possibility of using unipolar conductors, practically turns on the question that, where two are employed, although one of them is for all practical purposes at earth potential, in the event of the breakdown of the positive conductor the polarity of both may be reversed, and a complete reserve is thereby provided.[1] Otherwise the advantages

[1] In the opinion of the writer the same advantage would be secured by a double unipolar system, while many difficulties of the double insulated system would disappear.

are all in favour of the single insulated systems, and it simply remains a question as to the possibility of designing a unipolar system giving the necessary freedom from breakdown without introducing other objectionable features. This point is raised further in connection with mixed systems.

This point also has a bearing on the insulation of car equipments. It must be borne in mind that it is possible that the car may have to run on a section in which either (i.e. + or −) pole may be earthed. It is therefore necessary that the whole equipment should be capable of standing the full line pressure to earth.

With the trolley system, in which the negative pole is earthed, the magnet coils are usually at the earthed end of the circuit, and are therefore only subject to a pressure corresponding to the drop in voltage through them, but under the above circumstances they may be subjected to practically the full line pressure. The same remark applies to electromagnetic brakes should they be employed.

Design.—The conditions which have to be considered in designing a conduit are comparatively simply stated. They are:—

1. The provision of suitable arrangements for the efficient draining of the same, and for the removal of foreign matter collected in the conduit.
2. The design of the conduit tube itself so that it has ample strength to resist the crushing strains due to traffic or the strains tending to close the slot due to any expansion of the pavement.
3. Reasonable accessibility for the replacement if not for the inspection of insulators, conducting rails, and their fixings.

All these are simply questions of design, and present no very special difficulty where the track is simple. As soon, however, as it is necessary to deal with points and crossings a number of further difficulties present themselves.

The material used in construction of the conduit tube adopted in all modern installations consists of concrete, which forms the bottom and walls of the tube. In this at regular intervals are embedded cast-iron or cast-steel yokes, which carry and hold in position the rails forming the slot and the roof of the conduit.

The insulators, as mentioned above, may be fixed in various manners: in some of the early systems, for example, the Love and the Bentley-Knight, the insulators were attached to the yokes; the more modern practice is to attach them to the under side of the slot-rail.

It is obvious that at crossings two conduit tubes will intersect, and at such points four overhanging corners occur which have to be correspondingly strengthened. Sufficient strength for this purpose, however, is obtained by placing the yokes as close as possible to such a crossing-point and bolting the slot-rails together. On the other hand, in the construction of a point this difficulty is very considerably increased, as a long centre tongue in the track paving has to be efficiently supported in such a manner as to leave sufficient section in the conduit for the passage of the plough, the conductor-rails being interrupted in such positions. Steel constructions are usually employed for this purpose, and the cost of this special work is one of the most expensive items in the construction of a conduit line.

Centre versus Side Slot.—The lines constructed in New York, Washington, Nice, and Bordeaux, and the new lines of the London County Council, are built with the slot in the centre of the track. Paris at first adopted the side slot, but after constructing about 20 miles of track the centre-slot system was finally adopted, and is now to be used throughout. In some cases, however, the local authorities have objected to the centre slot, as in Berlin, Brussels, and Budapest, consequently in these places, as also in Bournemouth, the slot is formed in the groove of one of the track rails. This latter arrangement has the advantage that the third set of rails is avoided, and if no inspection-boxes are placed over the insulators the line presents a similar appearance to that of an ordinary horse tramway, it being practically impossible to see the slot unless the individual is standing almost vertically over the slot-rail.

This would appear at first sight to be the ideal solution for a conduit

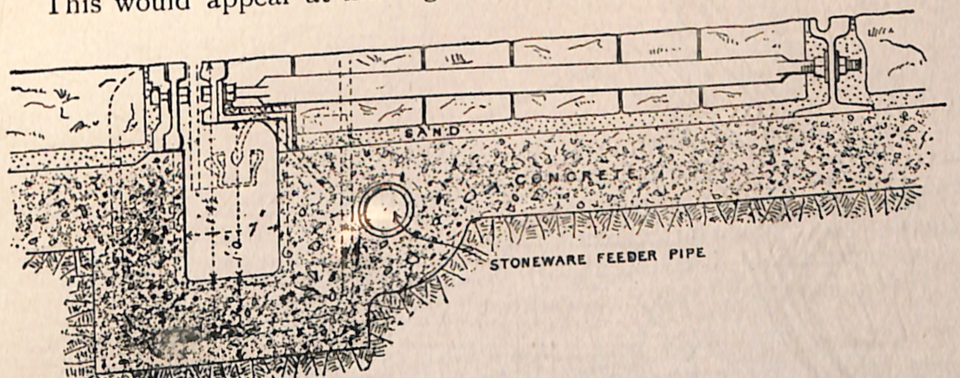


Fig. 167

system; various other considerations, however, soon present themselves. First, the conduit being under one of the track rails, it is obvious that this will have to be constructed of sufficient strength to carry the maximum weight due to a fully-loaded car, which, with those in use at the present time, may easily amount to 3 tons per wheel, which is considerably greater than the loads carried by ordinary traffic, which are not likely to exceed 1½ to 2 tons per wheel.

For the same reason it is desirable that that slot-rail, which in this case is also the wheel-rail, should have a vertical web, and this has the effect of reducing the distance between the slot-rails at their base, thereby confining the construction of the plough. A more important objection is that the wheel flanges throw mud and dirt on to the plough, thereby tending to reduce the insulation of the same. Where a single conductor conduit is employed, as in the Simplex (or Waller-Manville) system, it is quite possible to arrange the track slot-rail with a vertical web in such a way as to be supported during its whole length upon the outer wall of the conduit, the single conductor being placed in the conduit under the slot-rail on the inner side of the track (see fig. 167). In an unsymmetrical conduit of this type the wheel-rail is fully supported, and the insulated collecting-shoe being out of line with the slot will not suffer from mud or water thrown to the same extent.

The inherent difficulty, however, of the side slot is the point.

With the centre slot a comparatively light movable tongue can be used to guide the plough, but in the case of the side slot the tongue will have in one position to deflect and carry the car wheels, requiring therefore to

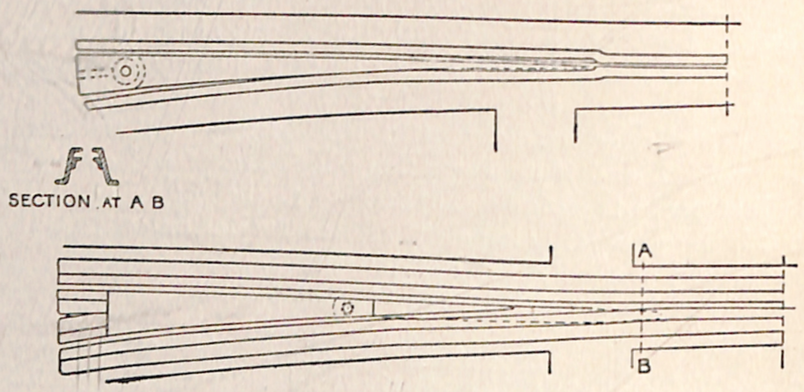


Fig. 168.—Centre-slot Switch

be much stiffer and stronger in order to carry the strains involved, and necessitating the surface over its whole length being flush with the roadway. Further, where only the plough has to be deflected, the angle of the point may be made much more blunt, and the length of the tongue and corresponding overhang is consequently considerably reduced (fig. 168).

In order to avoid this disadvantage in point construction with the side-

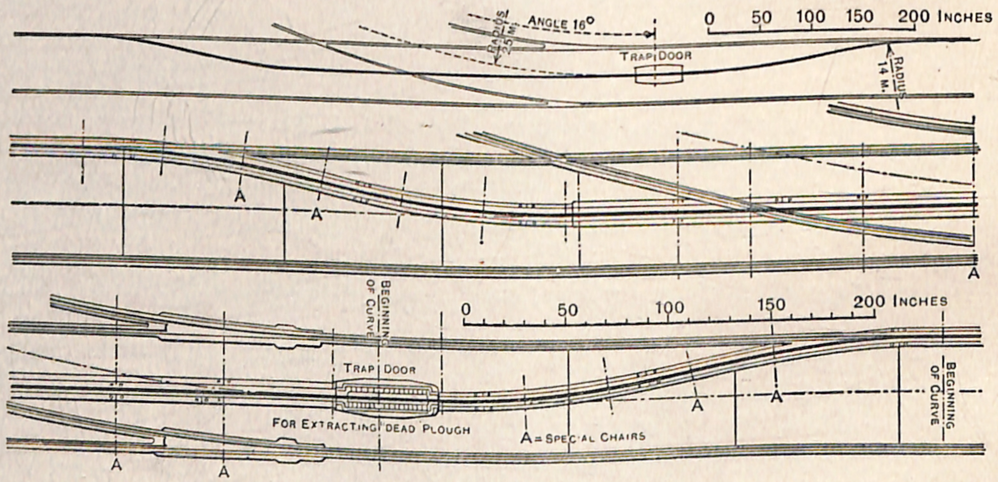


Fig. 169.—Deflection of Side Slot to Centre Slot

slot system, the slot is diverted to the centre of the track at points, thereby leaving the track points the same as with an ordinary tramway track (see fig. 169). Where this arrangement of diverting the slot to the centres is adopted with a side-slot conduit, it follows that the number of points which would normally occur with a centre-slot system is increased to the extent of the points where the slot turns out from the side to the centre, i.e. one extra for every branch.

Where points occur it is obvious that the plough must be guided to take the same path as the car; failure in this respect is one of the sources of breakdown to which conduit systems are liable. Serious accident, however, can be guarded against if the plough is free to move on a slide passing the whole width of the car, so that, in the event of plough and car taking different roads, the plough can travel along the slide (and either fall out or move clear of the car; this, however, is seldom likely to occur, as the driver will probably notice the failure before this happens and reverse his car).

In connection with the question of side-slot lines a further point arises, as to whether the slots should be on the same side, the inside or the outside of the tracks. Where the plough is suspended from a sliding arrangement enabling it to travel freely the full width of the car, this becomes quite immaterial from the point of view of the designer, and in such a case placing the slots on the two inner track rails will have the advantage that the slot-rails will be at the highest part of the roadway, and will have

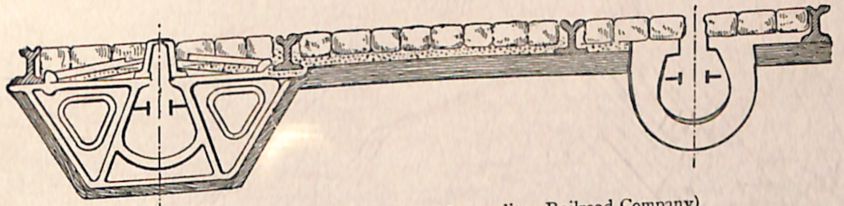


Fig. 170.—Washington Tramways (Metropolitan Railroad Company)

nearly all road matter swept away from them. In either of the other arrangements, one or both of the slots will be liable to have a considerable portion of the road sweepings swept into them.

This arrangement has the additional advantage during construction that it confines the deeper excavation work to the centre of the roadway, and if it is possible to take in hand the construction of the full width of the track at one time, it allows both conduits to be put in together.

Details of Construction.—In the New York and Washington systems the yoke is of the type shown in fig. 170; that is, in addition to the central position forming the section of the conduit and carrying the slot-rails, the yokes have an extension on each side carrying the track rails, and to which the latter are bolted. This construction was inherited from the cable conduit, and a similar arrangement has been adopted in other places with centre-slot. Where, however, as is usual in this country, a good foundation of concrete of from 7 to 9 inches in depth is laid under the full width of the track, these extensions of the yokes are unnecessary, as the track is sufficiently solid without them.

The first question which is involved in designing the yokes is the depth of the conduit. This depends, in the first place, on the size, section, and weight of the conductors it is intended to adopt, the insulators to be employed, and the method of fixing same, also to a certain extent on the class of paving to be used, as this latter point determines the depth of the slot-rails.

Slot-rails.—

Depth of Slot-rails.—With granite-sett paving the slot-rail depth cannot be much less than 6 to 7 inches; with asphalt paving, on the other hand, it may be reduced to about 4 inches.

The slot-rail forms in reality the crown of the conduit, and, as it has therefore to be sufficiently strong to carry the weight of any road traffic which may pass over it, a certain minimum strength is necessary, but the actual depth, as above mentioned, is really determined by the class of paving to be adopted.

As regards the width of the head of the slot-rails, from considerations of traffic it is desirable that these should be kept as narrow as possible; on the other hand, it is necessary to provide a sufficient space below the head in order to accommodate the nuts of the tie-bars which connect the slot-rails to the yokes and hold them in position. As these tie-bars are of necessity run at an angle to the vertical, these nuts will not lie flush on the inner surface of the slot-rail, but would be required to be supported by a bevelled washer, and the head of the slot-rail has to be of sufficient width to cover these and at the same time allow sufficient clearance for the passage of the plough.

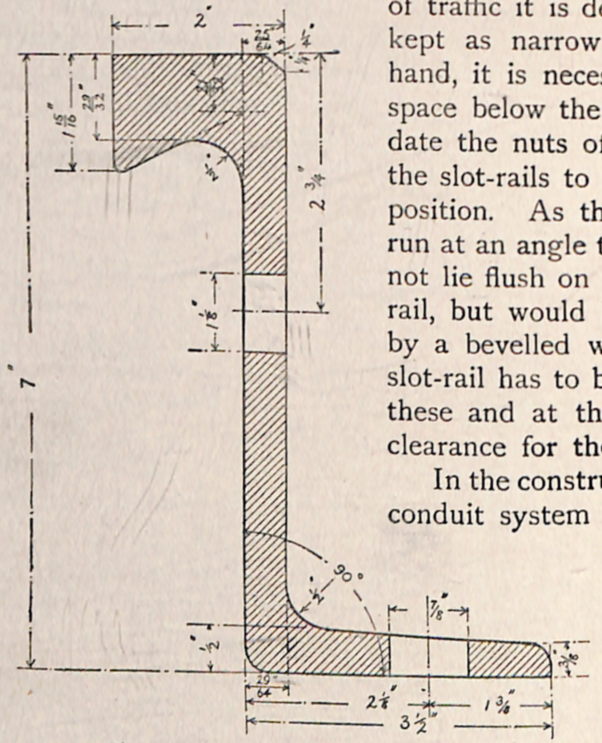


Fig. 171.—Section of Slot-rail, 60 lbs. per yard

In the construction adopted on the London conduit system this width has been reduced somewhat by the device of putting in a bend in the tie-bar just before passing through the slot-rail, the web of the rail being vertical. (See fig. 172.) Experiments made on these bars show that it requires about 11 tons to straighten them, and that the breaking strain is about 13 tons, showing that the disadvantage of introducing this bend is by no means serious.

Fig. 171 shows a section of the slot-rail. The two rails are set so as to make the slot $\frac{3}{4}$ inch in width, and the surface so as to be $\frac{3}{8}$ inch higher than that of the wheel-rails.

Width of Slot.—The width of the slot is much more important with centre-slot systems than with side-slots, where a rail groove of $1\frac{1}{16}$ to $1\frac{1}{4}$ inches already exists. Where the side-slot is adopted in this country it is probable that the bottom of the groove will be narrowed by a lip on one of the slot-rails, reducing the slot to about $\frac{3}{4}$ inch, as in the centre-slot system.

An all-important consideration in large towns is to reduce, however, the depth of the conduit as much as possible, so as to reduce to a minimum the outlay which it may be necessary to make in shifting heavy gas- and

water-pipes from beneath the track, the cost of which work may involve in some cases very great expense.

Also, in order to prevent any closing of the slot due to the expansion of the paving, the yokes have to be sufficiently strong to resist any strains that may occur, and it is obvious that any increase in the conduit depth will considerably increase the weight of the yokes necessary to ensure this.

Detailed dimensions of the yokes which are being employed on the

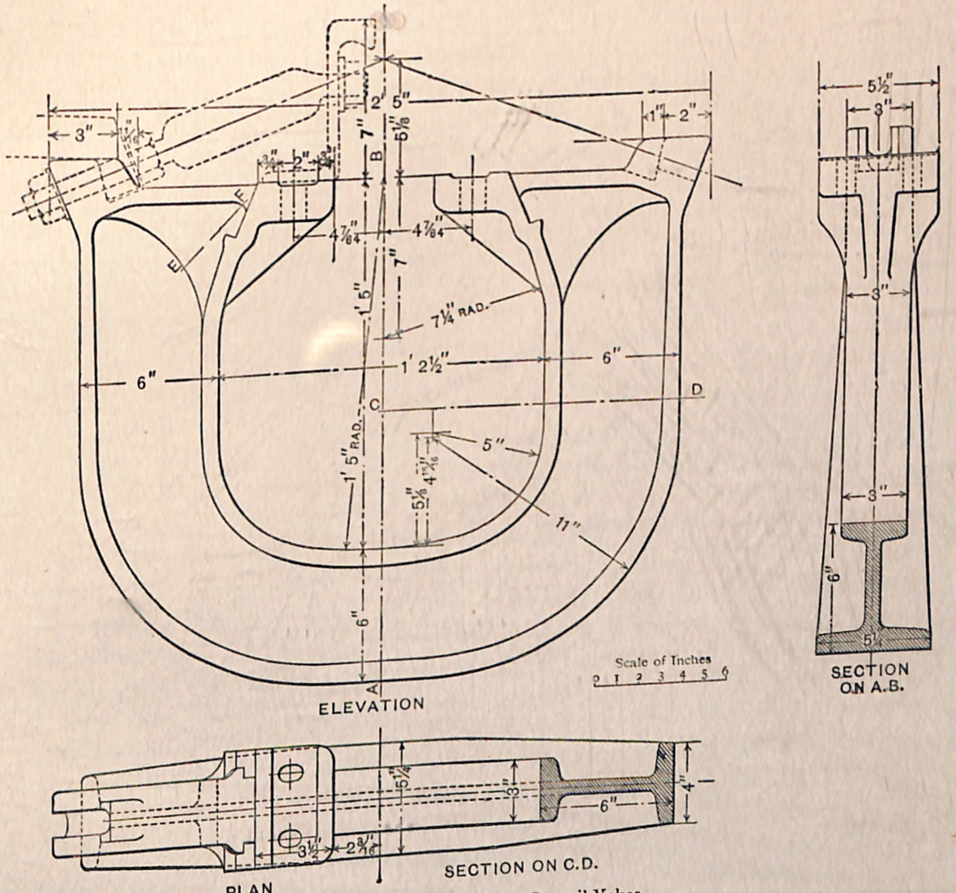


Fig. 172.—London County Council Yokes

London County Council tramways are given in fig. 172, the design being an extremely simple one. The general form of the yoke is similar to the letter **U**. The top of the yoke is provided with a seat for the slot-rails, to which they are bolted, and also with a lug for the tie-bars. There is, in addition, a seat for a plate which comes at the bottom flange of the slot-rail, to prevent the comparatively weak corner of concrete there from breaking away. The yokes are spaced every 3 feet 9 inches from centre to centre. This comparatively close spacing of the yokes has the advantage of not requiring an inordinately heavy yoke, and at the same time making a better provision against the danger of slot closure by pressure on the slot-rails between the yokes. Vertical and horizontal sections are shown to the right and below respectively.

Clearance below Conductor-rails.—Experience has shown that it is desirable to have a clear depth of not less than 6 inches, but preferably somewhat more, between the under side of the conductor-rails and the floor of the conduit, in order to readily carry off any water or other debris which may find its way into the conduit, without making contact with the conductor-rails.

Where the conductor is only cleaned periodically it is desirable to have much more, say 8 inches at least. In cases where the gradients of the side streets or the conduit line itself are likely to lead, in the event of very heavy rainfall, to flooding of the line, this contingency can best be provided against by decreasing the distance between the drainage-pits rather than enlarging the size of the conduit channel.

Unless special reasons exist for reducing the conduit depth to an absolute minimum, the space below the conductors may therefore be taken at 7 inches.

Height of Conductor-rails.—In determining the distance of the conductor-rails from the road surface, in addition to the depth of the slot-rails, sufficient clearance has to be allowed for air insulation, and the limiting dimension in this respect is that between the top of the conductor-rails and the under part of the yoke seat (see fig. 172).

This distance should hardly be less than $2\frac{1}{2}$ inches, which, with $1\frac{1}{2}$ to 2 inches in the yoke seat itself, gives 4 to $4\frac{1}{2}$ inches between the top of the conductor-bar and the under side of the slot-rails, or with a 7-inch slot-rail 11 to $11\frac{1}{2}$ inches from the surface of the roadway to the top of the conductor-rail as the *minimum* distances.

The actual distance is, however, determined largely by the method of fixing the insulator, by which this minimum distance will probably be somewhat increased.

Assuming, however, that the insulators can be fixed to support the rail at this height, and a conductor-rail $3\frac{1}{2}$ inches deep, we obtain on the above basis for ordinary purposes $7 + 4\left(\frac{1}{2}\right) + 3\frac{1}{2} + 7 = 21\frac{1}{2}$ to 22 inches as the minimum depth of the conduit for ordinary construction.

If the height of the slot-rail can be reduced below the size above given, and in special cases for short distances (as in crossing railway bridges) the free space in the conduit below the conductors is also reduced, the minimum conduit depth may be still further lessened accordingly; but, generally speaking, the above represents the minimum depth which it is advisable to employ.

Width of Conduit.—The conduit width depends on the width of the conductor-rails, and the distance between them plus the air-space necessary for insulation purposes. In the London County Council conduit this amounts to $14\frac{1}{2}$ inches.

With conductor-rails of opposite polarity it is hardly possible to reduce this, but were a unipolar system to be adopted, or in particular a single-conductor system, there is no doubt a reduction is possible.

In the Waller-Manville system, where a flexible conductor is employed, the width is reduced to about 7 inches (see fig. 173).

Conductor-bars.—In the above calculation the depth of the conductor-bars was taken as $3\frac{1}{2}$ inches. It might in some cases be reduced, but it must be borne in mind that the surface of contact has not only to have sufficient conducting area, but also a good bearing surface so as to suffer no appreciable wear.

Contact may be made either vertically or horizontally. The form of conductor now most usually employed consists of a T angle-iron turned sideways ⊣ ⊢, the flat heads being turned inwards and forming the working contact surfaces.

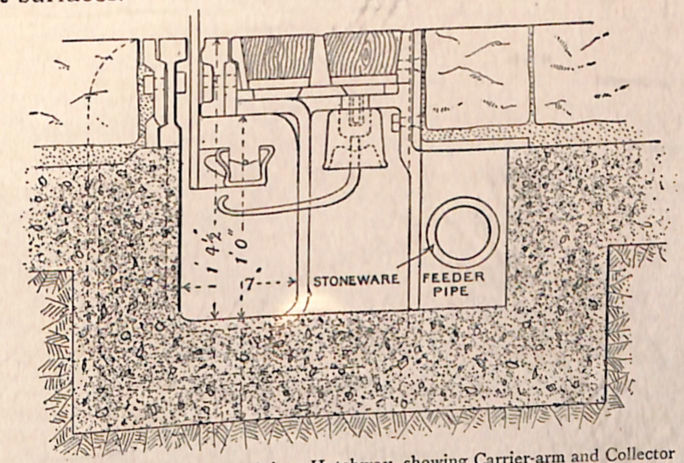


Fig. 173.—Cross-section of Conduit at Hatchway, showing Carrier-arm and Collector

Copper conductors have been used at Blackpool and in some other instances. Copper has, of course, a much greater conductivity than iron or steel, but, on the other hand, it does not wear so well, and the section provided to secure good working contact and bearing surface is in most cases quite sufficient, when steel is employed, to carry the current without excessive drop.

Further, owing to the advisability of subdividing the line into $\frac{1}{2}$-mile sections, on account of the security it gives in dealing with possible insulation faults, the employment of copper conductors loses what slight advantage it might have had. Where the line has not been sectionized in this way, and it has been found necessary to increase the carrying capacity of the conductor-bars, this can be more cheaply done by laying a copper cable of suitable capacity at the back of each conductor-bar than by using copper conductors. They are electrically bonded at sufficiently short intervals to the steel conductor-bar to prevent any possible electrolytic action between the two metals.

The material which has proved itself most suitable up to the present time is mild steel, which has a carrying capacity of about one-tenth of that of copper, or, speaking generally, the drop (per mile) is given by the formula

$$v = 0.4 \times \frac{A}{B},$$

where B denotes the sectional area in square inches, and A the current in amperes.

At the ends of sections, and at points and crossings where gaps occur, two insulators are fixed, to give additional mechanical strength.

Fixing of Insulators.—Various arrangements have been adopted for fixing the insulators in position. They may be divided under three classes. The oldest plan, employed in most of the earlier conduits, was that of fixing the insulators to the yokes. This method, however, has been abandoned owing to the necessarily confined space available at these points.

A second method of fixing was tried in New York, namely, that of supporting the insulator at the top of a pillar from the bottom of the

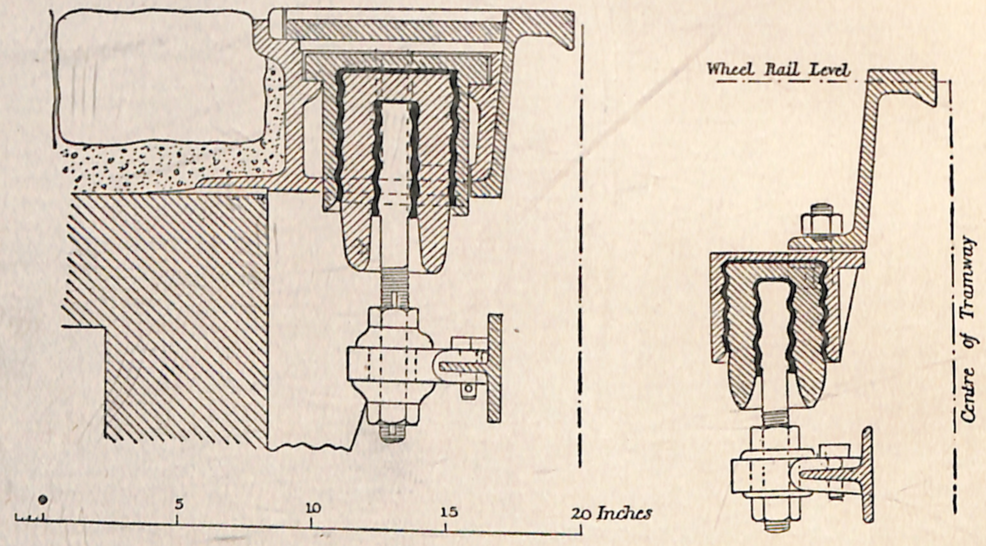


Fig. 174.—In Washington

Fig. 175.—In Paris

Central Conduit. Insulators and suspended Conductor-rails.

conduit. This method has, however, the disadvantage that it placed an obstruction in the free channel of the lower part of the conduit, and gave rise to difficulties in cleaning.

By fixing the insulators between the yokes it is possible to enlarge, without difficulty, the width of the conduit in these positions, and leave room for the employment of a large and efficient insulator. They are fixed in position either by bolting direct to the slot-rails, or by being fitted into insulator-boxes which are in turn bolted to the rails. Both these latter methods have been employed in comparatively recent constructions (see figs. 174 and 175).

In places where the use of these road-boxes is objected to—and it must be admitted that the absence of these boxes, two at intervals of say every 15 feet, greatly enhances the appearance of the roadway—it becomes absolutely necessary to sink the insulators, and in such cases it is usual for the insulators to be bolted to the under side of the slot-rail, as in fig. 175.

Design of Insulators.—The primary considerations to be borne in

mind in designing the insulators are those of insulation and mechanical strength.

Insulation.—As in most systems the insulators are fixed at distances of about 15 feet apart, it follows that there will be for each conductor about 350 per mile, or a total for both conductors, on a system of 10 miles of conduit, of not less than 7000 insulators. The design of an insulator which shall be thoroughly effective, and which shall maintain its insulation under the conditions of conduit working, is therefore very important.

The insulators employed on the first line installed in New York were built up of mica, &c., round a central bolt; they failed, however. In Brussels the insulating material employed is an india-rubber composition, which has on the whole proved fairly satisfactory. It has the disadvantage, however, of being expensive, and deteriorates in the course of time by exposure to the atmosphere.

The material which has proved itself thoroughly satisfactory is porcelain, and there is no reason that can be urged against its employment.

From the circumstances of the case it is only natural that the insulators should be liable to become covered with mud and dust, and for this reason the insulating surfaces should be as far as possible vertical or inverted. The most satisfactory shape is a type of "petticoat insulator", in which the central bolt projects underneath and carries the rail, while the whole of the upper portion is enclosed in a metal cap, provided with a lug or lugs for bolting the insulator in position, and a cape for throwing off any water or mud which may fall on it.

The central bolt is fixed in the insulator, and the insulator in the cap, by means of Portland cement, the opposing surfaces being corrugated in the manner shown in the drawings.

Mechanical Strength of the Insulators.—The insulator must be sufficiently strong to carry, first, the conductor-rail, and also to provide against any stresses produced by the passage of the contact-ploughs.

Where T conductor-rails are employed, the rails being in lengths usually of 30 feet and weighing about 20 lbs. per yard, the weight of rail to be borne by each insulator will be about 100 lbs.; the pressure exerted by the plough contacts in this case will probably not exceed 3 to 6 lbs., this pressure being, however, usually in a direction at right angles to that of the weight. These forces act at a point which is probably some 3 to 5 inches away from the axis of the insulator.

Figs. 174 and 175 give sections of the insulators used in Washington and Paris; in the former the insulator is accessible by a road-box, and is probably fixed as high as possible; in the latter the insulator is entirely below the slot-rail, and probably represents the minumum advisable dimensions, both for securing mechanical strength and providing sufficient length of insulating surface. The height of this insulator is 7 inches, or, including the length of the stalk, 12 inches.

Roadwork.—The usual course adopted in constructing a conduit system is to first of all clear the surface of the track and excavate the trenches for the conduit. Small concrete blocks spaced at the correct distances are then placed in position, and the yokes placed upon them, levelled, and bolted up to the slot-rails. When this has been completed, formers, constructed either of wood or metal sheeting in such a way as to allow of their easy removal after the concrete has set, are placed inside the yokes to shape the walls of the conduit, enlarging pieces being put in to provide the extra space required by the insulators. The concrete is then put in, forming the walls of the conduit and the under-bedding of the track. When this has set, the formers are removed by loosening them and sliding them along the conduit; insulators and contact-rails are then fixed in position, and after the track rails, tie-bars, insulator-boxes, if any, have been fixed in position, the track may be finished off in the usual manner.

Fig. 176 shows plan, horizontal, longitudinal, and vertical sections of the conduit put down by the London County Council.

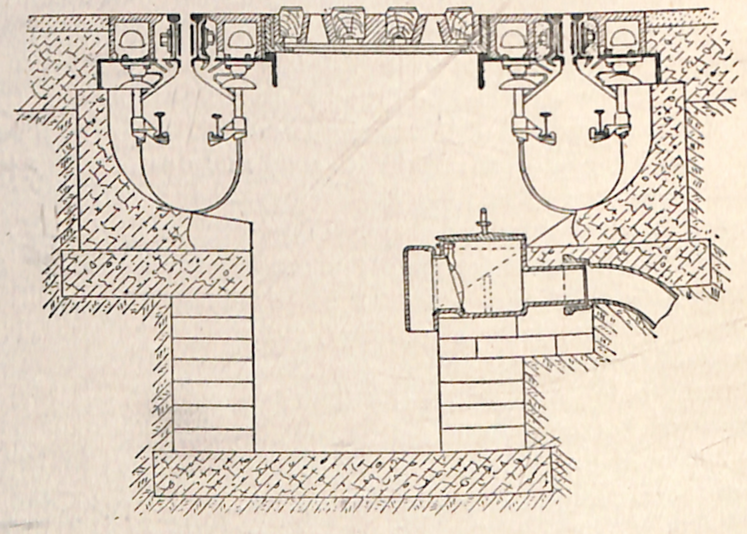


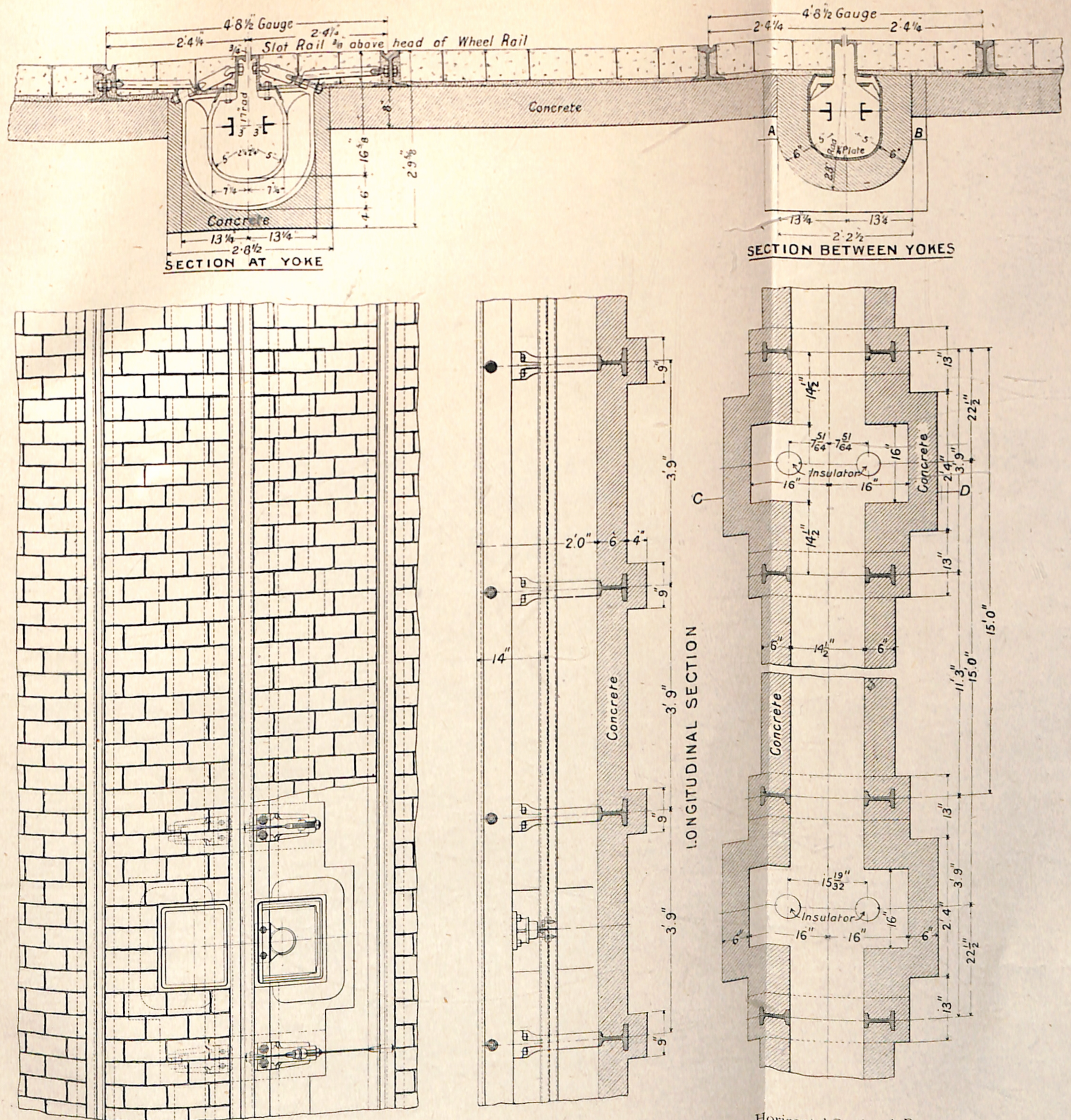
Fig. 177

Full dimensions are given, from which it may be noted that the depth of the conduit is about 24 inches, and the total excavation 2 feet 10 inches from the level of the surface.

The insulator chambers are also shown, the extreme width of the conduit at these points being 2 feet 8 inches, as against $14\frac{1}{2}$ inches normally.

At the yokes the concrete is 8 inches thick, so as fully to embed them except at the inner surface.

Drainage and Feeders.—The method of construction indicated above is straightforward enough, but it is broken at intervals by the arrangements required for draining. These consist of sump pits, into which the dirt and other debris which falls into the conduit finds its way or is carried by means of the scrapers. In the first line constructed in New York these pits were very large, being 2 feet 6 inches wide by 4 feet deep, and extended the full width of the track. They occurred at every rail joint, i.e. 30 feet apart, the idea being to render the joints in the slot and conductor-rails and the main insulators easily accessible. In Brussels they are placed in the centre of the double track, as shown in fig. 177, and occur at intervals of every 130 feet.



Plan of Single Track

Conduit

Horizontal Section A.B.

Fig. 176.—Details of Conduit Arrangements for London County Council Tramways

To face IV, 198

The design of such a pit must be such that it is easily accessible for cleaning out, while the water outlet must be so designed as to carry off rapidly such large quantities of water as might possibly find their way in in the event of flooding or heavy downpour, while at the same time

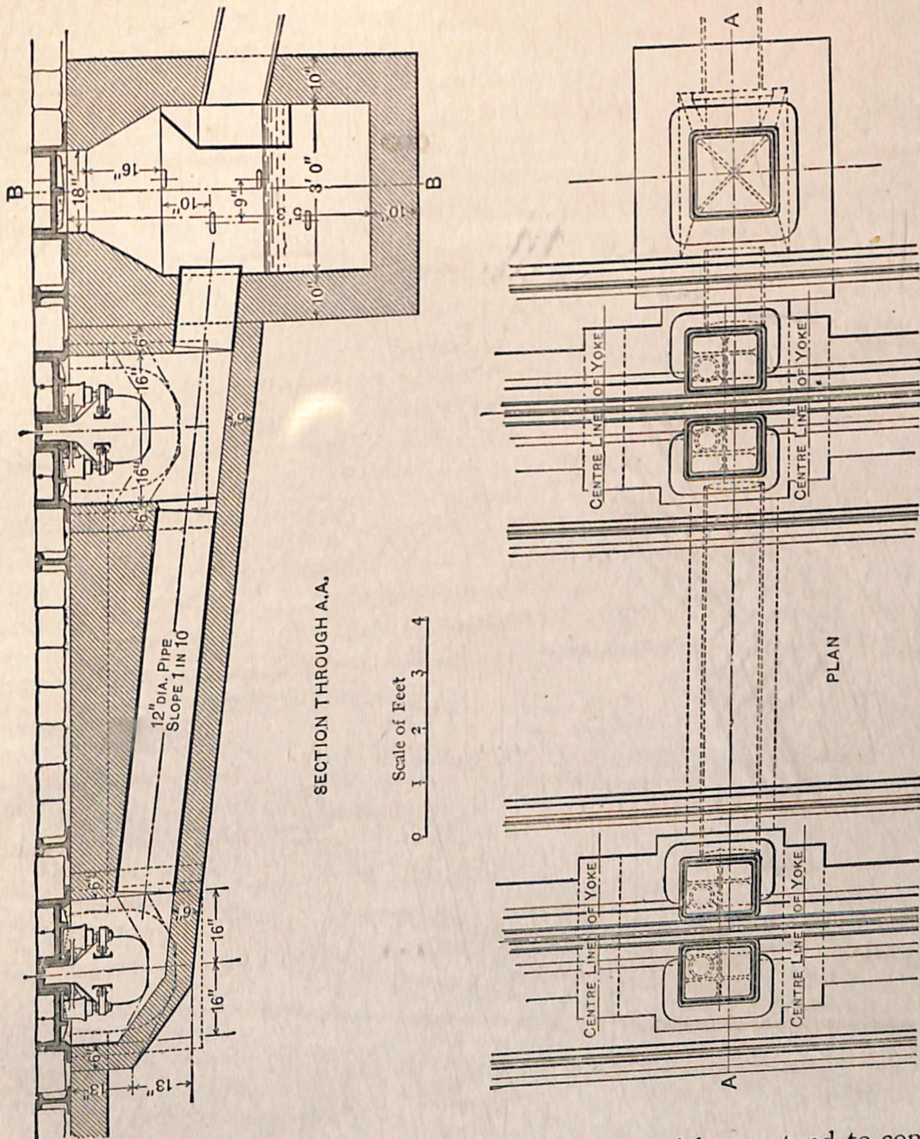


Fig. 178

retaining the solid matter and stopping any gases which may tend to come back from the sewer. The distance apart at which these pits should be placed depends on local conditions, liability to heavy rain, and other considerations.

On the London tramways it has been considered necessary to space them at distances of about 40 yards apart. They are placed entirely outside the track, and are connected to the conduits by means of a 12-

inch pipe having a fall of 1 in 10. The chambers are built of concrete, have an internal diameter of 3 feet and a total depth of about 5 feet 10 inches from the surface of the roadway. Over the connection to the sewer a cast-iron hood is placed, as shown in fig. 178, to keep back any gases which may come through from the sewer, the outlet being placed at such a height as to leave about 2 feet from the bottom of the pit to the water-line. This construction may be much more readily cleaned out than the ordinary siphon trap.

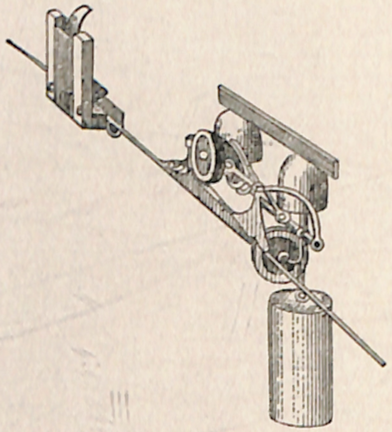


Fig. 180.—Tension-gear

Before finally leaving the question of the conduit design, special attention may be called to the Waller-Manville system, as affording a contrast to the rigid double-insulated deep conduit being employed at the present time, in that it utilizes a single-insulated conductor, with an earthed return, the conductor being flexible, and also as being the only conduit system essentially differing from the above which it has been seriously attempted to introduce within recent years.

As has already been explained, the great objection made to the employment of flexible conductors is the difficulty of keeping the conductor strained. This is effected in the above system by the employment of a special straining device shown in fig. 180. The flexible conductor is supported at the position where this gear is fixed by an arm carrying three pulleys, round which it passes to the tension-weight, which keeps the conductor taut. The arm is free to rise and fall with the conductor as the car passes; and as the last pulley carries the conductor through the point of suspension, and the pull of the conductor on one side of the arm is balanced by the corresponding pull on the other, these forces are in equilibrium, and no twist is exerted on the insulators. At curves, arms of similar construction are employed, which hold the conductor in such a way as to leave it free to move. Where such arms are used two insulators are fixed. Further, it is claimed that as, with the exception of curves and some special positions, the conductor is not attached but only rests on the insulators, from which it is lifted by the plough, no strain is thrown on the insulators by the latter

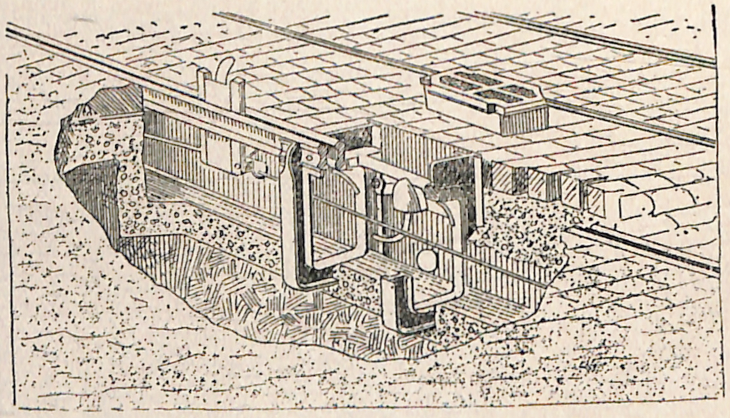


Fig. 181

in passing, and that therefore a much smaller and lighter insulator can be employed.

Fig. 181 shows a section of the track and conduit between hatchways, from which it will be seen that the running slot-rail is directly carried by the yokes and the wall of conduit; the conductor, being carried under the overhung side, is thus protected from anything entering accidentally the slot. Owing to the comparative lightness of the special copper conductor employed, it is not necessary to place the insulators closer than about every 30 feet, i.e. only about half the number are necessary, and they may be conveniently fixed in an inspection-box formed by two yokes placed close together at the rail joints. It is also possible to remove and renew the conductor through the slot, and this operation can be performed in a very short space of time. The great claim made on behalf of this system is that the actual depth required for the conductor being only that necessary to allow for the sag in the same between insulators, the total depth of conduit required may be considerably reduced, the shape of the conduit being such as to allow of its being very readily kept clean either by hand or by an attachment to a certain number of the cars. The shape and size of the conduit renders the construction of points in the side-slot much simpler than when the wider conduit necessitated by the use of double insulated conductors is employed.

The Plough.—We now come to the construction of the plough, which is probably the most difficult problem involved in conduit construction.

The plough must be so designed that it is of ample strength to resist the various shocks to which it is subjected, and at the same time it must be sufficiently weak, so that, in the event of obstruction, the plough shall break and come away rather than that injury should be caused to the conductor-rails and insulators. In addition to this, the plough is that portion of the whole system which is subjected to most wear and tear, while at the same time the proper insulation of its parts is of vital importance to the working of the system, and its dimensions, owing to the space available, have to be reduced to the smallest workable minimum. It consists of three portions, the contact-shoes (or "flappers"), the shank, and the suspension gear.

Fig. 182 gives the construction adopted on the conduit lines in London. The contacts consist of cast-iron shoes which are pressed outwards against the vertical faces of the conductor-bars by means of semi-elliptical springs which maintain a pressure of about 3 lbs. The work of moving the contact-shoes along the face of these conductors, however, is not performed by these springs, but is performed by links attached to the shank, as shown in the drawing, which are so arranged as to limit at the same time the outward movement of the shoes. This has the advantage that it only necessitates a comparatively small splay in the conductor-bars at points of interruption, and greatly lessens the shock caused when the plough enters at these points. A copper fuse is inserted between the contact-shoe and the conductor in the shank, which would blow in the case of the insulation of the plough breaking down, thereby cutting the faulty plough out of circuit. The shank consists of two steel cutting edges connected by two plates enclosing the conducting leads, and thickened on each side by renewable hard-steel wearing-pieces, the thickness of the latter being about $\frac{1}{8}$ inch. In the boxed space formed by these plates the insulated conductors have to be carried, either of which may be subjected at any time to the full working pressure of the line. The thickness of the whole arrangement with a $\frac{3}{4}$-inch slot does not exceed about $\frac{1}{2}$ inch, as with the most

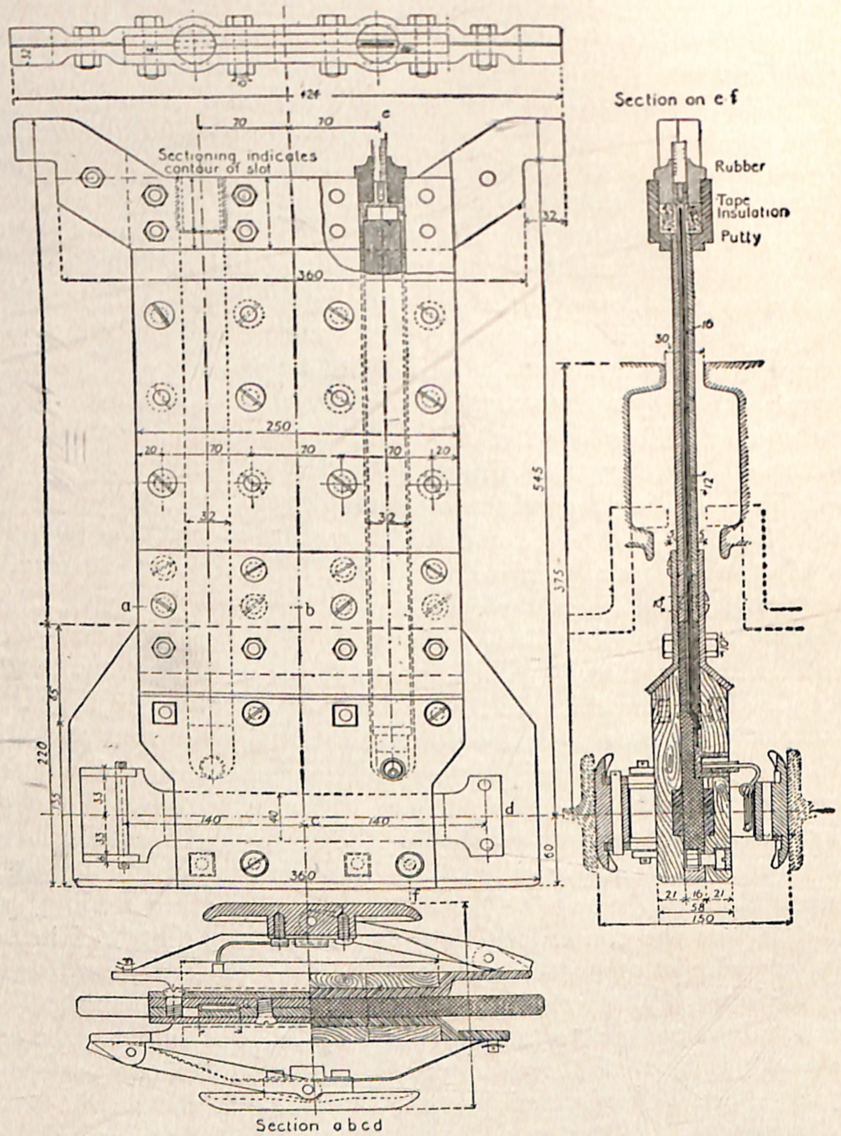


Fig. 182

careful setting the slot has been found under some circumstances to close to $\frac{5}{8}$ inch.

The insulation of the two conductors in the plough is one of the weakest points in a conduit system, and probably gives rise to more break-downs than any other cause. As a rule no difficulty arises in dry weather, but incipient faults begin to develop directly wet weather sets in. In Paris the plan is adopted of providing a double equipment of

ploughs, i.e. a duplicate set is kept in depot, and after a wet day the ploughs on the whole of the cars that have been out are changed, those taken off being thoroughly dried out and well soaked in insulating compound. This plan has proved thoroughly successful, and breakdowns from this cause have been reduced to a negligible quantity.

Another method of constructing the shank is to make the cutting edges slightly thicker than the box portion in the centre. They then not only carry all the strains, but are subject to all the wear, and must in consequence be easily replaceable. As these cutting edges must form the main groundwork of the shank, the first construction is probably much the simpler to maintain as regards wear, while in the second the insulated conductors may be more readily accessible. The Simplex plough was constructed in this way, and is shown in fig. 183. There being only one conductor the contact is on one side only, and forms a bed on which the flexible conductor rests. The centre portion is easily renewable.

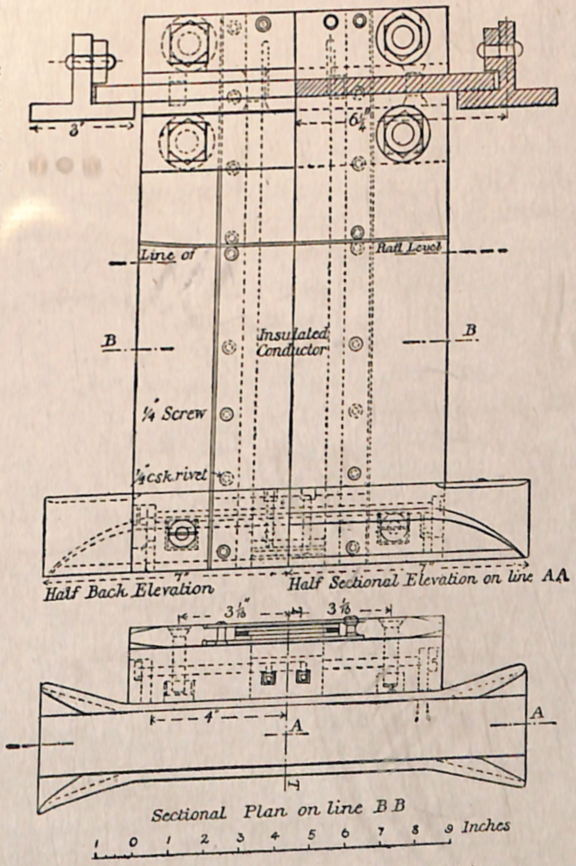


Fig. 183.—Details of Collector. "Simplex Conduit

Suspension Gear. — Where the cars will only have to run on a conduit track, and it will not be necessary to raise the plough out of the conduit, the suspension gear is comparatively simple. For reasons already explained it is very desirable that the plough should have a free movement across the full width of the car, and slides should be provided for this purpose, but they should be so constructed that while allowing the plough freedom to turn slightly to follow freely the course of the slot, they must at the same time prevent any tilting due to any slight obstruction met with in its progress. In Brussels, where the side conduit is used, provision is only made for lifting the plough out of the conduit, the driving arrangement being designed with a certain amount of lateral play so as to allow the necessary freedom for taking curves, &c. As the conduits are constructed on the inside of the track, and on the return journey the conduit will be on the other side of the car, it becomes necessary at the end of the journey to provide conduits under each track rail, the cars being fitted with two sets of ploughs.

Where, however, a mixed system is employed, the construction becomes complicated with the gear necessary for raising the plough out of the conduit, and becomes practically part of same.

Mixed Systems.—Owing to the cost involved in its construction, the conduit system will never be employed for the outlying portions of a tramway's network, and it follows therefore that while its employment in the central portions may be justifiable, unless a special set of cars are to be put aside for the working of the section so constructed it will be necessary to so arrange the car equipment as to be able to work on the overhead or some other systems as well as the conduit.

This involves either (1) the disconnection of the plough from the car, or (2) its removal from the conduit, i.e. either the plough shall be carried continually on the car, being raised up when not in use, or removed and replaced on the car at each junction of the two systems.

The latter would appear to be the simpler method, a manhole of convenient size being provided under the track, arranged so that a man can carry out the necessary operation each time the car arrives at these points. Very little consideration, however, will show that this arrangement is undesirable and rather expensive. It has, however, been successfully used at Washington, the point in question being a natural stopping-place for traffic purposes, and the plough is removed without lengthening the stop made by the car. It is quite true that in some such positions, where points at the same time occur and where there is a very heavy traffic, it will be necessary to keep an extra man in attendance; but, even under these circumstances, he is likely to be of more use above-ground.

An arrangement, therefore, which retains the plough on the car is one which is more to be recommended. The simplest and neatest solution is to raise the plough out of the conduit through the slot without any special alteration to the slot. This has been successfully done both in Brussels and Berlin, the plough being so designed as to allow of its removal from the ordinary width of slot in use at those places.

Plough-raising Gear.—At Berlin, in fact, the arrangement is almost automatic. A wheel is fixed to the under side of the plough, and, an inclined plane being constructed at the end of the conduit section, when the car reaches this point the wheel comes in contact with this plane and forces the plough gradually out of the slot, when it is raised clear of the track by turning a crank. All that is necessary, therefore, is for the conductor at the same time to release the trolley pole and bring the wheel on to the overhead trolley wire. In Brussels the arrangement is slightly different, the plough being always raised by hand through the slot by the motor-man.

A second arrangement, also in use at Berlin, is shown in fig. 184. The plough is so constructed that it is automatically lifted out of the conduit in the event of the slot being obstructed by any foreign substance.

Where it is not possible to raise the plough through the slot, plough-hatches similar to that shown in fig. 182 have to be used. A mark is made

on the track showing the driver the exact position in which to stop his car. The driver raises the plough out of the slot, while the conductor opens the trap and places the trolley-pole in position. In Paris, where both side and centre conduits are in use, slides are provided to enable the plough to move the full width of the car frame, and at the same time hoisting-gear is provided for raising the plough out of the slot in the central position.

Earth Returns with Mixed Systems.—In connection with the subject of mixed systems it might be mentioned here that the usual practice, owing to the one side of the trolley system being earthed, is to employ for the conduit sections *entirely separate circuits and generating plant, with separate feeders* from the generating or sub-stations.

Unless this is done it means that the negative pole of the conduit line

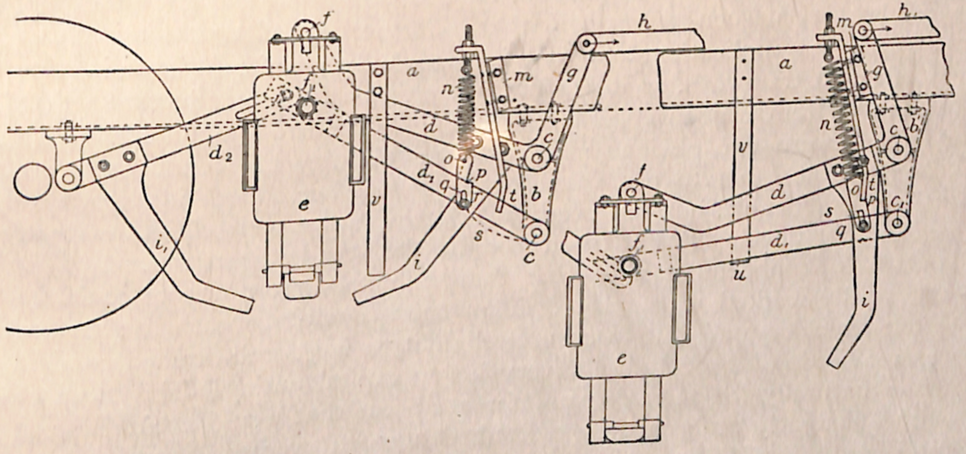


Fig. 184.—Plough-raising Gear, Berlin

is earthed by the trolley sections, and it is not possible to ascertain, therefore, the insulation of the negative conductor-bar.

In the author's opinion, however, no special disadvantage would occur even if the negative pole were earthed at the generating or sub-stations, as, owing to the drop in the conductor-bars, the greater portion of the negative bar would be slightly *above* earth potential, tending to improve the insulation.

Judging by the tests given on p. 186, the negative conductor-bar is generally (roughly about 10 to 15 volts) *below* earth potential.

The earthing of the negative pole would therefore obviate the necessity of running separate generating plant, or the putting down of sub-stations specially for the conduit sections, even if it were still necessary to retain separate feeders and switch-gear.

If the only final argument in favour of a double-insulated system is that the negative conductor forms a reserve to the positive, then it would be better to have two positive conductors used in parallel, entirely disconnected from each other, except at the feeding-points, through cut-outs.

Were a thoroughly reliable unipolar conduit system to be designed, the same machines might be run on both sections, while the complicated arrangement of the switch-board, with the throw-over switches, feeder-reversing switches, earth indicators, &c., would all be avoided with the negative pole put to earth.

CHAPTER VIII

SURFACE-CONTACT AND OTHER SYSTEMS

Introduction.—The earliest method of conveying electrical power to a moving vehicle appears to have been by means of a third rail supported on wooden blocks close to the surface of the ground.

It was very soon discovered that this method of transmission was limited in its application, and that it was wholly unsuited to use in connection with tramways, as it was necessary to place the conductor so that the danger from accidental contact would be reduced to a minimum.

There were two obvious methods—one to carry the conductor overhead and the other to place it beneath the surface. Both ideas proved entirely practicable, but the overhead system, on account of its low cost, was rapidly developed, and soon became the standard practice.

It was soon demonstrated that the conductor or conductors could be successfully worked when placed in an open conduit beneath the surface of the street or road, but to ensure reliability a large well-drained conduit was required, which entailed a very heavy capital outlay. This state of affairs naturally led to a demand for a system that would avoid the use of the unsightly and, as then erected, dangerous overhead wires without entailing the prohibitive cost of an open conduit.

To meet this demand inventors and engineers endeavoured to develop what is now known as the Surface-contact System.

This system essentially consists of a sectional conductor laid nearly flush with the surface of the street or in a small shallow conduit; a continuous conductor connected with the generating station, and insulated in any convenient manner; a series of switch devices which automatically, as the car passes them, make a connection between the continuous conductor and the respective sections of the sectional conductor when immediately beneath the car.

The earliest inventors in the field were the late Dr. John Hopkinson and Messrs. Ayrton & Perry, who both devised what were in effect surface-contact systems, but their object appears to have been to prevent excessive leakage from a long length of third rail

There are two general forms of making connection between the sectional conductor and the moving car. In one case the sectional conductor is mechanically continuous, having but short insulated gaps, and the contact is made by a brush or wheel carried on the car. In the second method the sectional conductor consists of a series of studs projecting slightly above the surface of the roadway, and usually placed 6 or 8 feet apart. The collector in this case is a skate-shaped shoe of sufficient length to reach

between two of these studs, and often so designed as to come in contact with three or four at the same time. Either of these methods of collection are applicable to most systems, although the stud system has been more generally used.

The waste of power in surface leakage is a factor that at first sight would appear to be a serious drawback in all systems of this class, but in practice it is found that under the worst conditions this does not reach an amount that would seriously interfere with the success of the line, varying from practically nothing in dry weather to about 5 amperes per car at 500 volts, the skate being in contact with two studs, and would probably not exceed 5 per cent of the total power required under average conditions. This, although a serious item on a large tramway, is not prohibitive. The amount of leakage current will not vary greatly whether the sectional rail and brush or the skate and contact-stud be used, for it is not practicable to raise the studs enough above the surface of the street to keep the skate clear of mud and water, and as the skate is always alive it presents as much surface for leakage as would a sectional rail.

Closed Conduits.—Another series of inventions, having the same object as the surface-contact systems, were known as closed conduits. They were small shallow conduits, having one or more continuous conductors, and they were provided with some means for keeping the conduit closed so as to exclude mud and water, except at that portion of the conduit beneath the car necessary to admit the plough to make connection with the conductors.

Fundamental Requirements.—The fundamental requirements of a surface-contact system are as follows:—

1. Certainty of the contact being established.
2. Certainty of the contact-stud being cut out after the car has passed.
3. Minimum projection above the surface of the street and minimum amount of metal surface exposed.
4. Moderate first cost.
5. Simplicity and minimum number of moving parts.

In regard to the first requirement it has been established that the certainty of pick-up is greatly enhanced by energizing the stud or sectional conductor before the collecting-device touches it.

The second requirement is in some respects even more important than the first, for if a stud or sectional conductor is left alive in the street, serious or even fatal accidents, either to horses or foot-passengers, will undoubtedly result. This, besides rendering the tramway liable for damages, would certainly cause the authorities to prohibit the system.

The Dolter System.—The Dolter system is shown in diagram in fig. 185, from which the working of the system can be readily traced. The contact-switch is clearly shown in fig. 186. It consists of a cylindrical box made of an insulating waterproof material, and hermetically sealed. Into the lower part of this box are laid the connections from the main feeder, which are permanently connected to a carbon contact located at one side of the cylindrical chamber. The contact-lever itself is L-shaped, very loosely pivoted at the top of the box, and falls by gravity in a vertical position away from the carbon contact at the side of the box.

The action of the system is clearly shown in figs. 187 and 188, which are partly diagrammatic. The contact-studs are of cast iron, B B, and are

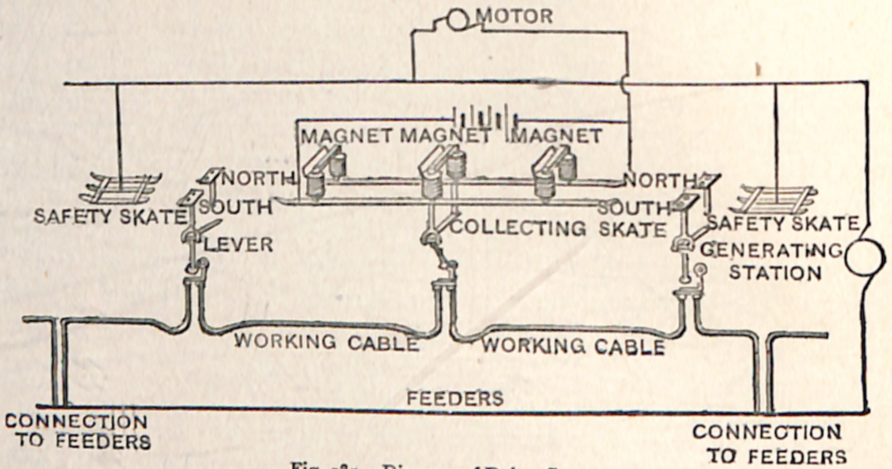


Fig. 185.—Diagram of Dolter System

embedded in a non-magnetic block, and separated from each other by a non-magnetic material *b*. The whole contact-stud and box rests in a manganese steel chair, F, embedded in an asphalt block, A A. The contact-skate consists of two long magnets energized by seven magnet coils placed at suitable intervals.

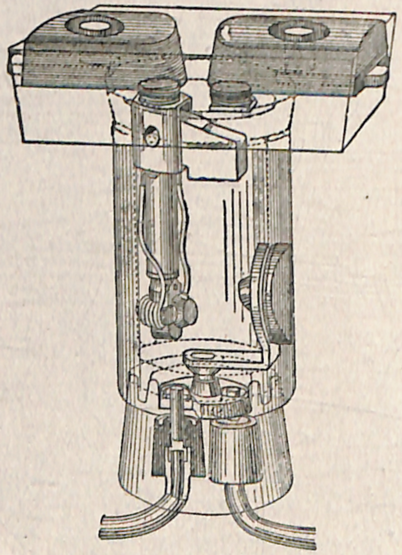


Fig. 186.—Dolter Contact-stud

Both these contact-skates are alive, and aid in collecting the current. Upon their coming into contact with blocks B B, a magnetic circuit is established from the blocks B B and contact-lever L, which is drawn up into the position shown in fig. 188, making contact with the carbon contact above referred to and one of the blocks B. Upon the contact-skate having passed the stud, the lever L falls back into its original position by gravity. The whole box can be lifted clear for inspection or replacement by raising the two catches shown in dotted lines on fig. 186. Sufficient slack is left in the cable to allow the whole box to be lifted clear of the hole, when the upper part of the box can be unscrewed from the lower as indicated in dotted lines on fig. 186.

A safety-skate is provided which, in event of the contact-lever L sticking in position and leaving the stud alive, would form a short circuit and blow a fuse in the contact-box.

The Lorain System.—The mechanical and electrical details of this system have been worked out with exceptional care, and considerable

judgment has been shown in selecting the most suitable materials for insulation and general purposes. The contact-boxes are placed between the rails at distances of about 10 feet, varying somewhat with the type of car used. A convenient number of these are connected to a distributing

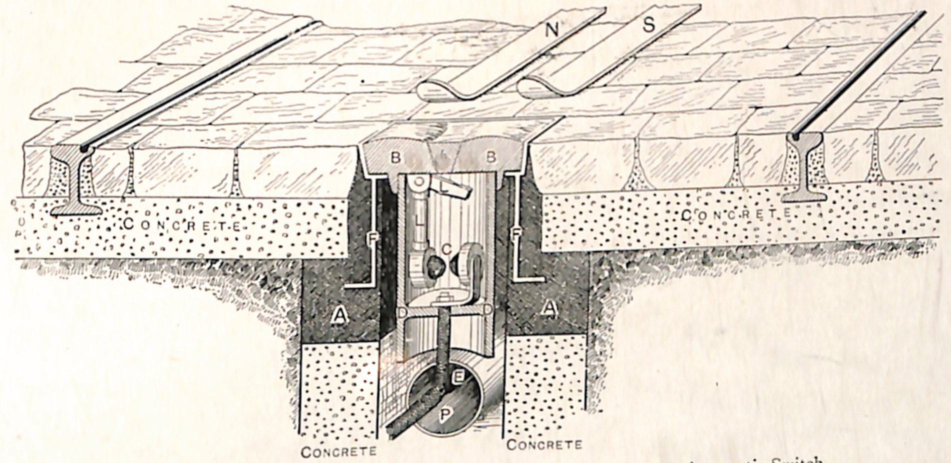


Fig. 187.—Dolter System—Skate approaching Stud, Circuit open at Automatic Switch

main which corresponds to the trolley wire, and is carried in a suitable duct with a Y-branch pipe at each contact-box.

The distributing main is then carried to a switch-pillar located on the footpath, where the connection is made to the main feeder. Any convenient number of groups can be run into one section-feeder pillar. These

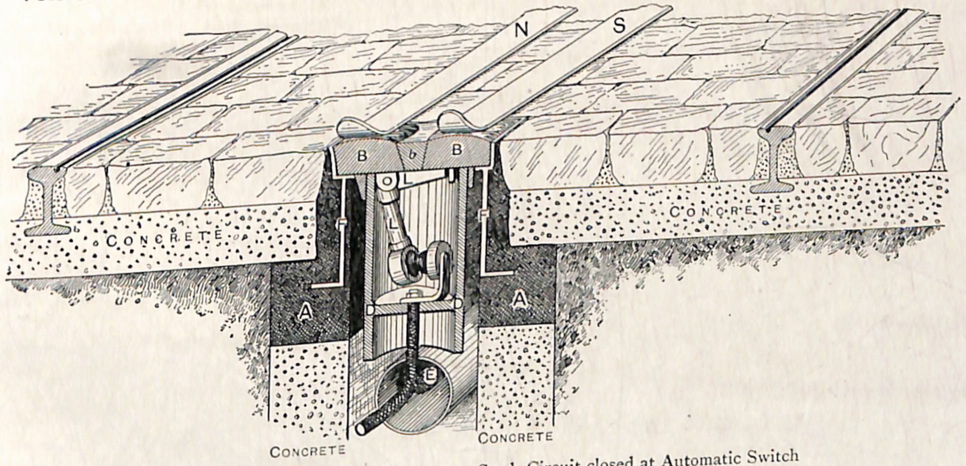


Fig. 188.—Dolter System—Skate over Stud, Circuit closed at Automatic Switch

pillars are usually placed a couple of hundred yards apart. This is shown diagrammatically in fig. 189. The contact-box is shown in figs. 190–93, and it will be seen that this is as simple as it is possible to make a switch of this description. It has but two moving parts, one of which is a flexible connection. The base of the contact-box W (fig. 190, but shown more clearly in fig. 193) is composed of reconstructed granite—that is, granite which has been reduced to powder, pressed into the desired shape, and subjected to a temperature of about 3000° F. The result is an insulating material of great strength and durability, entirely non-absorbent, acid-proof, and not affected by heat or cold—in fact, a material which is particularly suited for this class of work. Into this insulating block is fitted and secured by bolts a metallic cover L L′ (fig. 190), $12\frac{3}{4}$ by $6\frac{3}{4}$ inches. To this cover is fastened the mechanism of the switch, so that, by removing the two nuts shown, the entire switch can be removed for examination or replacement with a good deal of ease. The cover of the contact-box consists of three sections, two of which (L L′) are of iron, and the third (the centre-piece O) of special non-magnetic steel.

This is extremely hard and tough, and particularly well adapted to resist the wear of the collecting-shoe H. This part of the cover is the highest, and is about $\frac{3}{4}$ inch above the paving of the roadway. In the switch between the cover and the base is secured an insulating cup V V′, which contains the switch contact. This cup is made in two sections, and is hermetically sealed by means of a gasket and an annular screw-ring. The cup is of a moulded insulation, similar to that employed for overhead trolley-wire insulators, but of improved quality, and has brass-screw terminals moulded into the top and bottom. The top terminal is screwed into the steel cover O, and holds the cup in position. The bottom terminal is a spring clip forced over solid contacts which are connected to the distributing main, and the whole is held in place by the main bolts holding down the cover.

Into the circular hole in the base of the contact-block is fitted a brass gland, which is held in place by an annular screw-ring. This gland is screwed into the top of the Y-branch pipe above referred to, and has a disc fitted in the bottom, which is provided with two stuffing-boxes, through which are passed the ends of the distributing main, and the stuffing-boxes are packed tight on the lead sheathing. In the top portion of the gland is placed a disc of insulating material carrying the spring contacts above referred to, and also screw contacts for connecting to the distributing main.

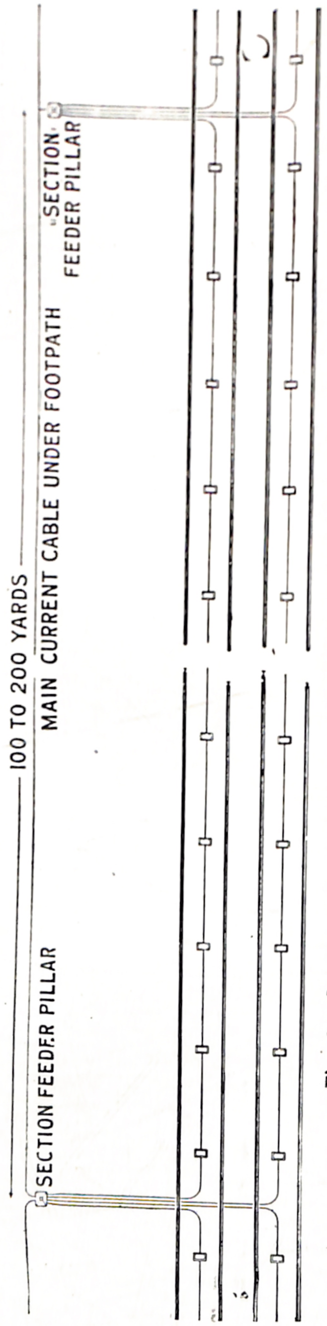


Fig. 189.—Lorain System—Diagram of Connections between Contact-boxes and Main-current Cable

The entire space around the outside of the cup and inside of the gland T T T is filled with a heavy insulating oil having a greater specific gravity than water. By this means water is effectually prevented from reaching the live portions of the circuit. Another method, which is not shown, but now considered preferable, is to lay the cables on the solid system, bringing the ends up into the bottom of the switch-block, and filling the space about them with bitumen. The switch itself consists of a soft-iron plate A, $4\frac{3}{4}$ inches by 2 inches by $\frac{1}{16}$ inch, weighing but $3\frac{1}{2}$ ounces. To this is secured a carbon-contact disc E about 2 inches in diameter.

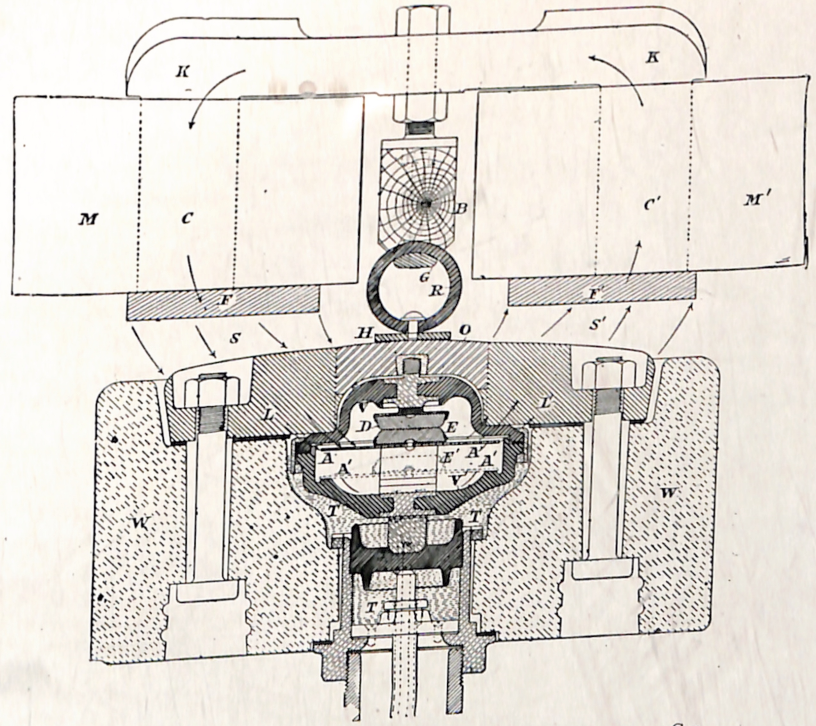


Fig. 190.—Section of Contact-box, Contact-shoe, and Magnet System on Car

A similar carbon disc contact D is secured to the brass terminal moulded into the top of the cup.

A hard-rolled copper ribbon, $1\frac{1}{2}$ inches wide, folded upon itself in Z shape, as shown in fig. 191, forms the electrical connection between the armature A and the terminal in the bottom of the insulated cup, which is in turn connected to the distributing main. The armature normally lies in the position A′A′ indicated in dotted lines in fig. 190, and clearly shown in fig. 192. The switch is actuated by an electromagnet carried upon the car, which is energized by the coils M M′. The lines of force pass through the yoke K K, the cores C C′, the pole-pieces F F′, the spaces S S′, the cover of the contact-box L L′. The armature A A is thus in a strong magnetic field, and is attracted upward, its carbon disc E forming contact with the carbon disc D. The electric circuit is thus established from the distributing main to the contact-stud O.

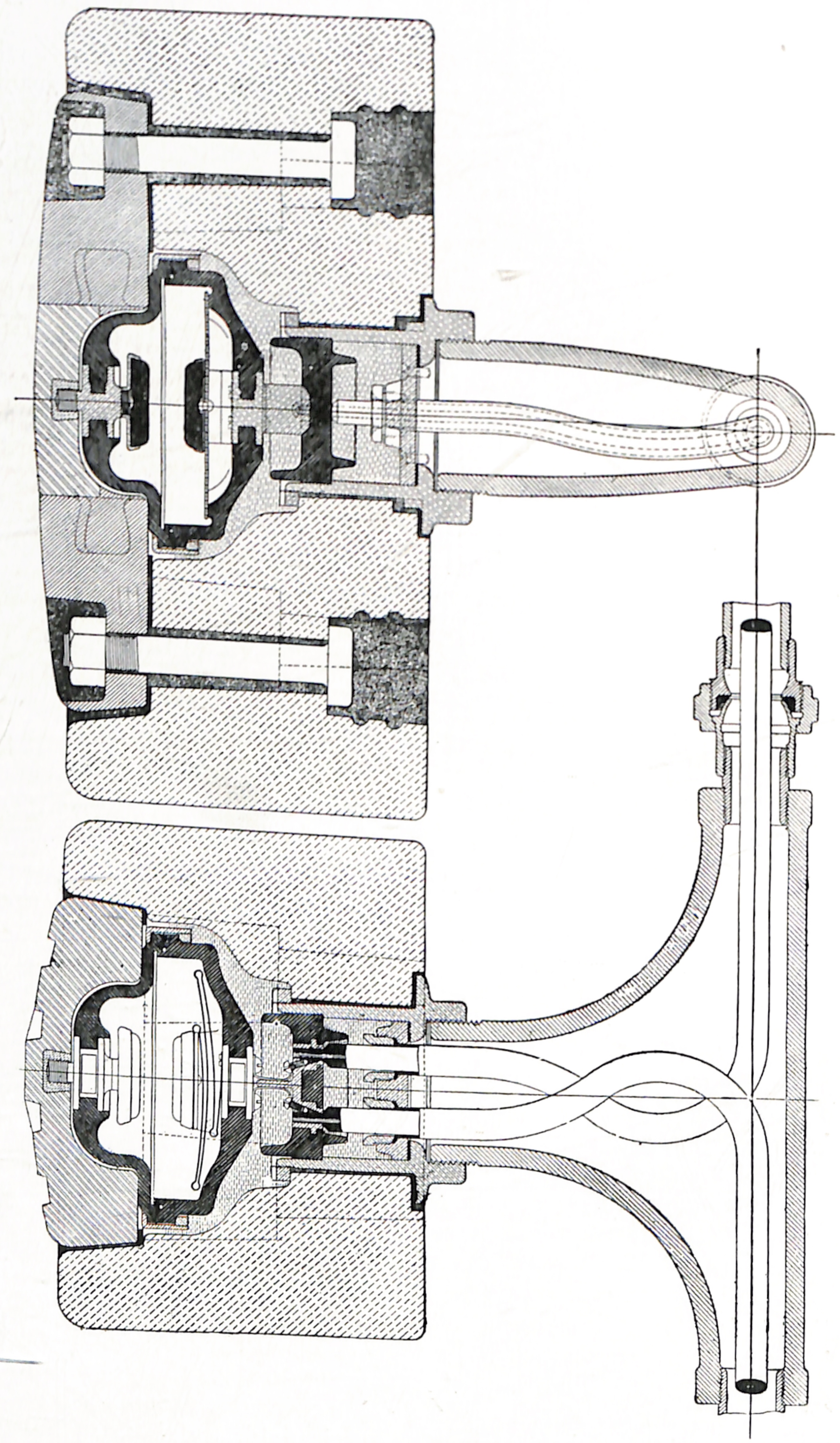


Fig. 191

Fig. 192

Lorain System—Longitudinal and Transverse Sections of Contact-Box

The current collector is about 12 feet long, or of sufficient length to a little more than bridge the distance between two studs. It is composed of a non-magnetic plate H, a piece of heavy rubber or linen hose R, and a wooden support B. This latter is secured to the yokes of the magnets by bolts so as to be adjustable.

As the contact between the discs D and E is entirely dependent on the pull of the magnet carried on the car, several of these magnets are required, six or more according to the length of the car.

The pole-pieces of each magnet are provided with strips of iron about 2 feet 6 inches in length and 5 or 6 inches in width, placed longitudinally with the car. The extended pole-pieces of the six magnets nearly touch

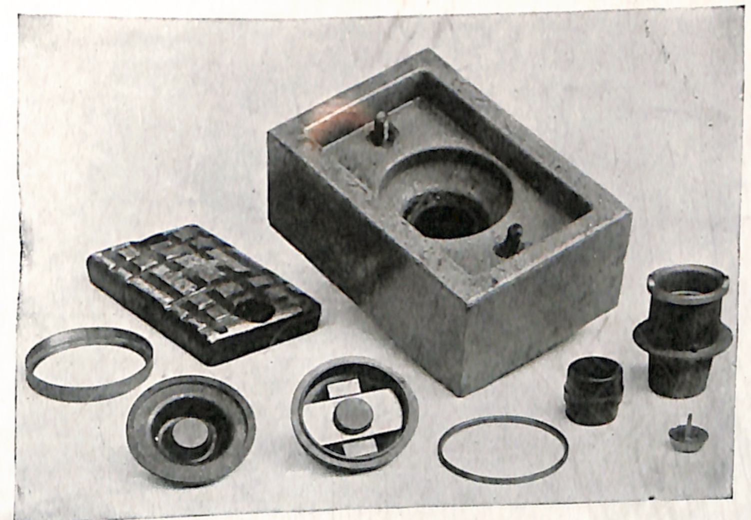


Fig. 193.—Parts of Contact-box (Lorain System)

each other, and are securely bolted to wooden distance-pieces, thus forming two continuous and parallel electric magnets, so that the magnetic attraction on the armature A A is practically constant during the whole time that it is under the skate. Details of the magnets and contact-shoe are shown in figs. 194 and 195. These parallel magnets are made somewhat longer than the collecting-skate, the result of which is that the stud is energized before the skate comes into contact with it. This adds greatly to the certainty of the contact being established before it has been broken on the preceding contact. The contact-skate also breaks contact with the stud before the stud passes out of the influence of the magnet. Consequently, if any arcing takes place it occurs between the stud and the skate, and not in the contact-boxes.

The magnet coils are provided with two windings, a series and a shunt. The shunt winding is connected across the main circuit, and requires about 1 ampere of current, and is always in use while the car is running. The series coils have a resistance of 0.175 ohm, and are connected in series with the motors, thus giving a contact pressure on the carbon discs D and E proportional to the amount of current transmitted.

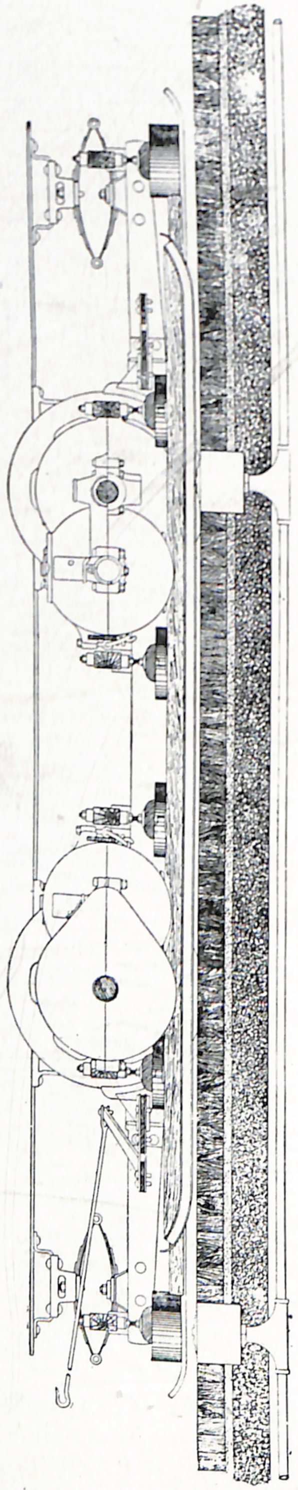


Fig. 194.—Lorain System—Longitudinal Section of Track and Motor Truck

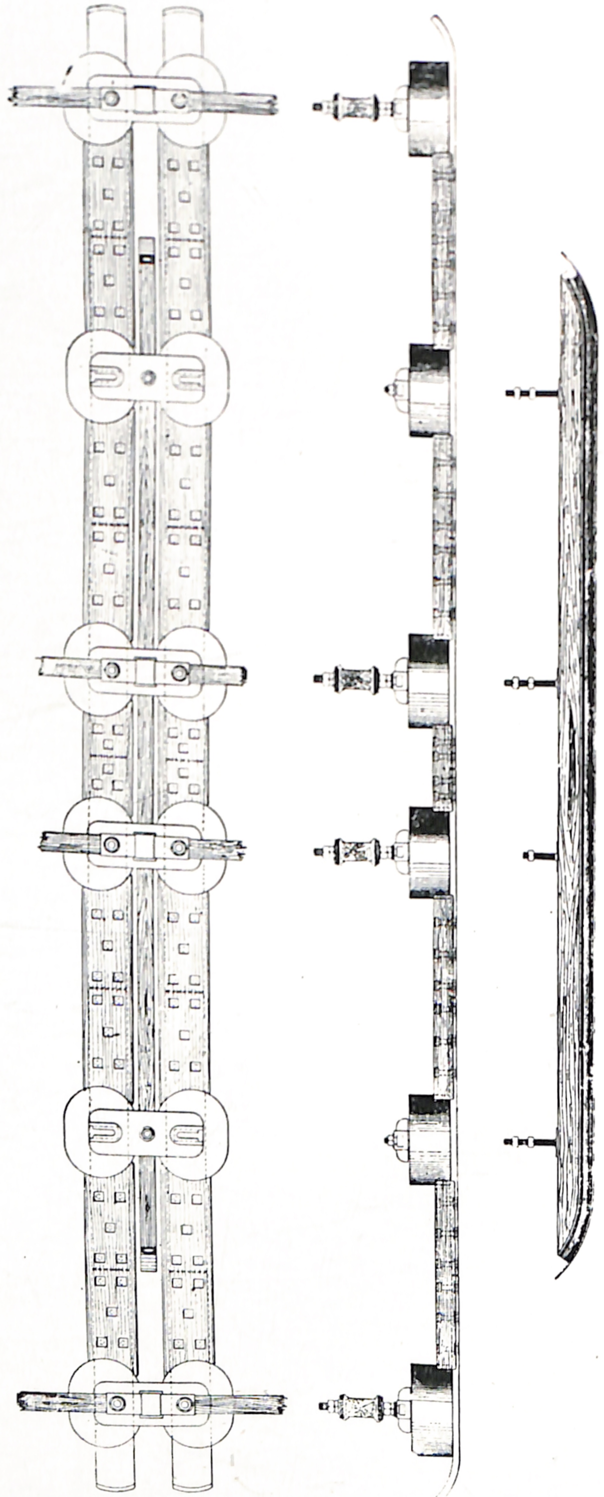


Fig. 195.—Lorain System—Plan and Sectional Elevation of Magnets and Shoe

The small storage battery is provided for picking up the first switch on starting. Arrangements are made for charging this battery without removing it from the car. A diagram of the car wiring is shown in fig. 196.

It will be noted that it is so arranged that the car can be run either from the overhead trolley or by the surface-contact system by the simple change of a switch. The ease with which this can be done is a distinct advantage

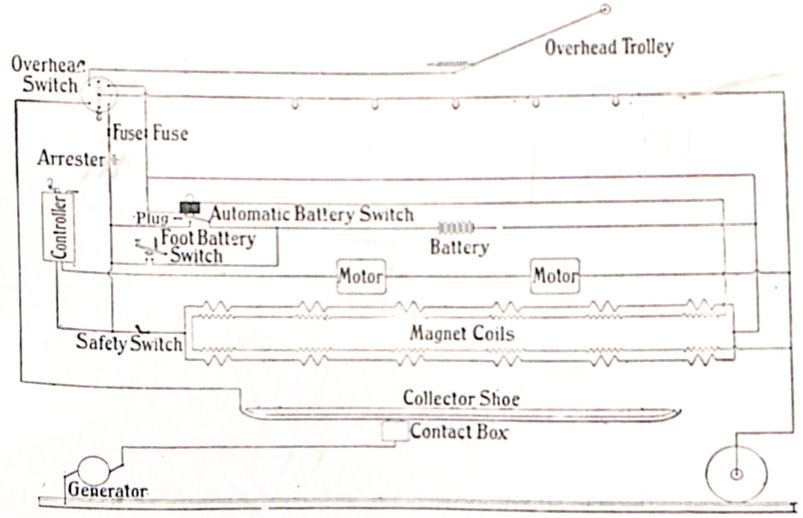


Fig. 196.—Diagram of Car Wiring as arranged for Combined Contact and Trolley Lines

of this system. An earthing device is provided whereby any stud left alive after leaving the magnets is short-circuited to earth, blowing the fuse or safety device in the switch-pillar.

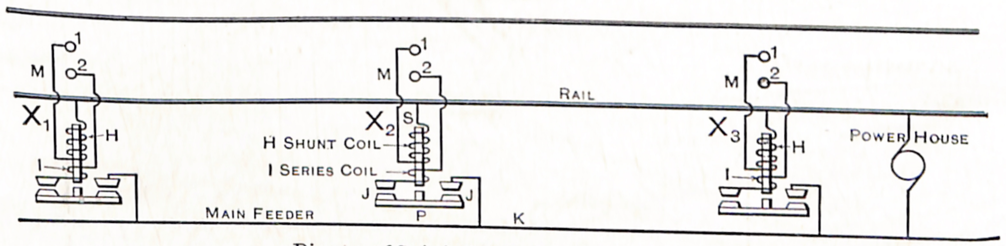


Diagram of Switch Connections (Westinghouse)

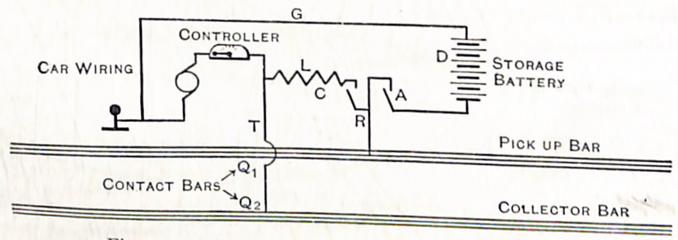


Fig. 197.—Diagram of Car Connections (Westinghouse)

The total weight of the magnets, collecting-devices, storage-battery, &c., is about 2000 lbs., equivalent to about 12 per cent of the weight of the car.

The Westinghouse System.—The Westinghouse system requires a shunt and a series coil to be used at each switch. The former establishes contact between the feeder and the contact-stud, and the latter increases the pressure of this contact. There are two series of studs, one used to actuate the shunt coil of the switch, and the other for drawing off the main current.

Fig. 197 shows the general arrangement of the system clearly in diagram. Each car is provided with two spring contact-skates, Q_1 and Q_2. These skates are mounted the same distance apart as the contact-studs 1 and 2. The contact-skates are long enough to come into contact with two studs at the same time. If a car is standing with the contact-skates in contact with their respective studs, for example at X_2, the switch A is first closed, which allows the current from the small storage battery D to pass through the

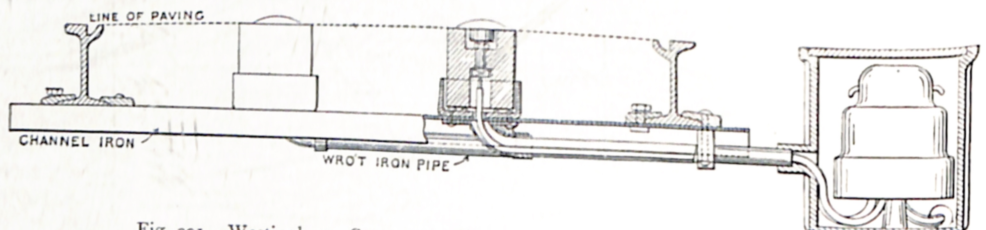


Fig. 201.—Westinghouse System—Section of Track equipped for Tramway Service

conductor R, to the skate Q_1, stud No. 1, and shunt coil H, to the rail. The current passing through the shunt coil H draws up the armature P, closing the switch and establishing a connection between the 500-volt main feeder K and stud No. 2, through the carbon contacts J J and series coil I. The switch C is now closed and switch A opened, cutting out the battery. The switch X_2 is kept closed by the current flowing through series coil I, stud No. 2, skate Q_2, conductor T, controller, and motors to rail. The current to close the advance switches now flows from T through resistance L, switch C, conductor R, skate Q_1, stud No. 1, conductor M, and coil H to the rail. As the car advances and the contact-skates make connection with the next

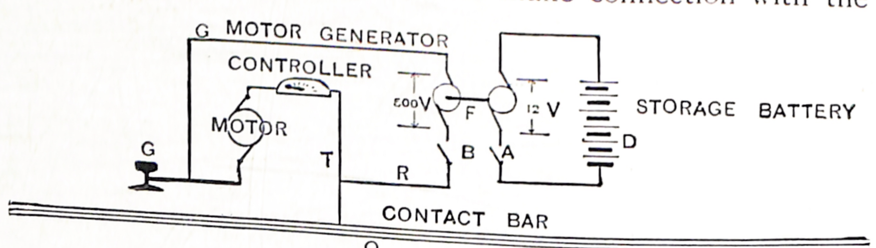


Fig. 202.—Westinghouse System—Diagram of Car Wiring

pair of studs at X_3, the operation becomes automatic, and the battery is not brought into action at all. As soon as the skates leave the studs the current ceases to flow, and the armature P falls back by gravity. As the coil holding the switch closed is in service with the car, it cannot open while there is any current flowing, so no arc occurs in the switch.

Details of the electromagnetic switch are shown in figs. 198 and 199 (see Plate). The switch magnet M is protected by an iron casing, and is provided with a fine-wire or shunt coil for the pick-up current, and a coarse-wire coil, which is in series with the main current. This magnet attracts an armature attached to a bridge-piece J, each end of which carries a carbon disc N. R R are guides for the bridge-piece. The carbon discs N make

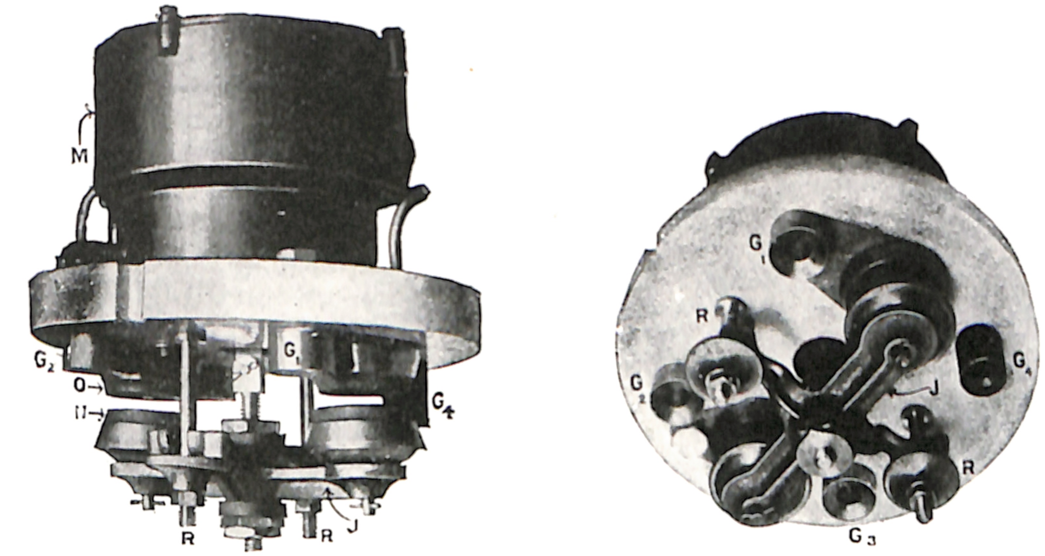


Fig. 198.—Westinghouse System—Details of Contact-Box, showing Switch

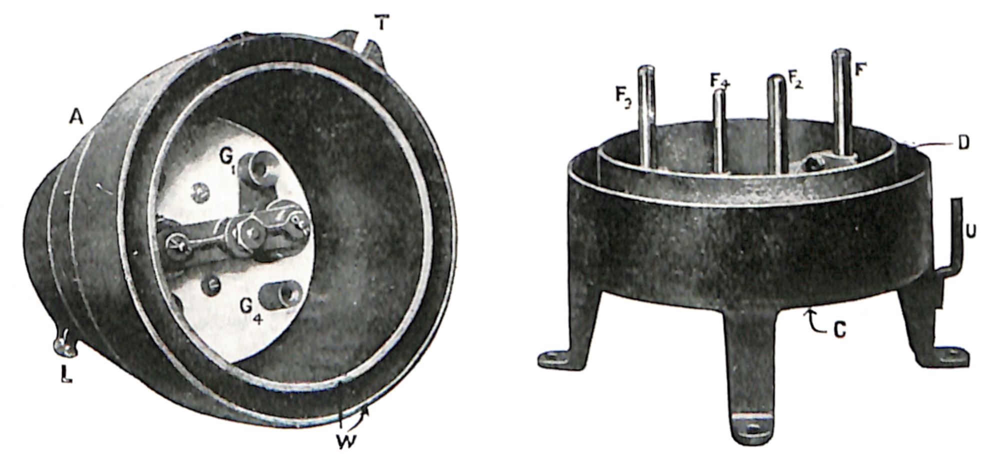


Fig. 199.—Westinghouse System—Details of Contact-Box, Switches removed

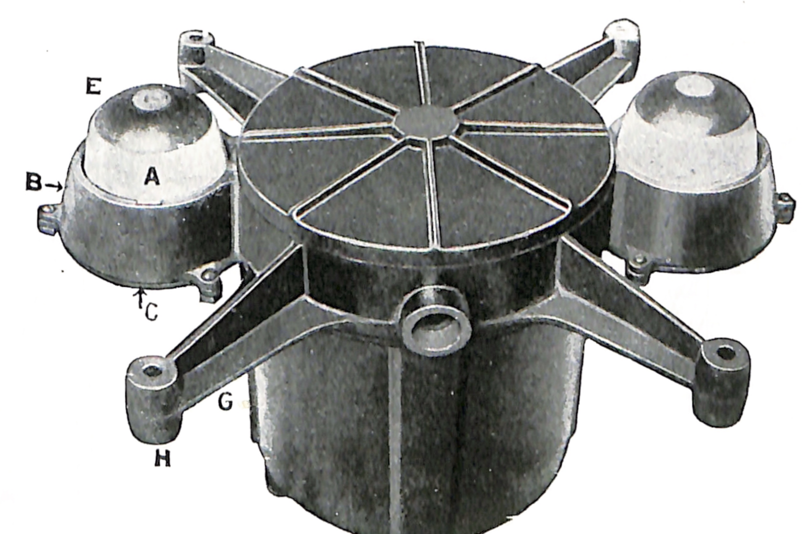


Fig. 200.—Westinghouse System—Switch-Box and Contact-Stud for Railways

contact with the carbon discs O, which are attached to the marble base of the switch. One of these is permanently connected with the positive main feeder, and the other through the series coil to the contact-stud 2 (fig. 197). It will be noted that the switch provides a double break for the current. A pan C (fig. 199) is provided with four pins F. These pins slide into receptacles G in the switch base; they are insulated from the pan C, but are provided with terminals for connection to the main feeder, rail, and contact-studs. The whole pan is filled with paraffin-wax after the connections have been made. The upper part of the switch is then slipped over the pan and sealed, on the diving-bell principle. This arrangement is made to provide for the easy removal of the switch for replacement or protection.

When the switch is designed for use on a railway it is combined with two contact-studs E, as shown in fig. 200 (see Plate facing p. 216), and supported by the four arms H to the cross-ties. If intended for use on a tramway, the arrangement used is shown in fig. 201. The switch mechanism is placed in a cast-iron box at the side of the track, and cast-iron contact-studs, embedded in suitable insulating material, are placed between the rails. The switches could, if so desired, be grouped together in convenient distributing-chambers located at some distance from the track. If it is desired to use only a single row of studs, the pick-up current must be at the same voltage as that of the main circuit. Under these circumstances the car wiring shown in fig. 202 is used. Switch A is first closed, which completes the circuit from a storage battery D through a small 500-volt motor-generator F. In a few seconds, when this has got up to speed, switch B is closed. The pick-up current then passes through conductor R to contact-skate Q, and then through the magnet switches, as previously described. As soon as connection has been established to the contact-stud the motor-generator may be stopped. This high-voltage pick-up is of advantage where the track is liable to be obstructed with snow and mud.

Thomson-Houston System.—In this system, as will be seen in referring to fig. 203, two rows of contact-studs are required. These are placed about 1 foot from the rail and are of two types—one a high-tension contact shown in section A B, fig. 204, and the other a low-tension stud shown in section C D, fig. 205. In both cases the contact-stud is embedded in a block of wood. In the high-tension stud the block rests on an iron chair, which is secured to two adjacent sleepers. In the low-tension stud the iron chair is carried up to form a box, the edge of which is flush with the surface of the paving. This box is connected by a suitable cable to the rail. Both studs are so designed that the wearing portion can be easily removed and replaced when worn down by the action of the contact-skate. The contact-skate is about 13 feet in length, which is sufficient to make contact with two studs simultaneously.

The action of the system can be followed from fig. 206. B, B_1, and B_2 are the high-tension contact-studs; A, A_1, and A_2 the low-tension studs. C, C_1, and C_2 are magnet coils which actuate a switch with three contacts. One of these contacts is permanently connected to the main feeder, the other two are connected to two adjacent high-tension contact-studs. The first movement of the controller closes the switches H and K. The closing of the switch K brings into action a small storage battery.

The current passes through a portion of the starting resistance of the motor, the skate E, contact-stud A_1, coil C_1, to the rail, and thence back to the battery. The battery current energizes

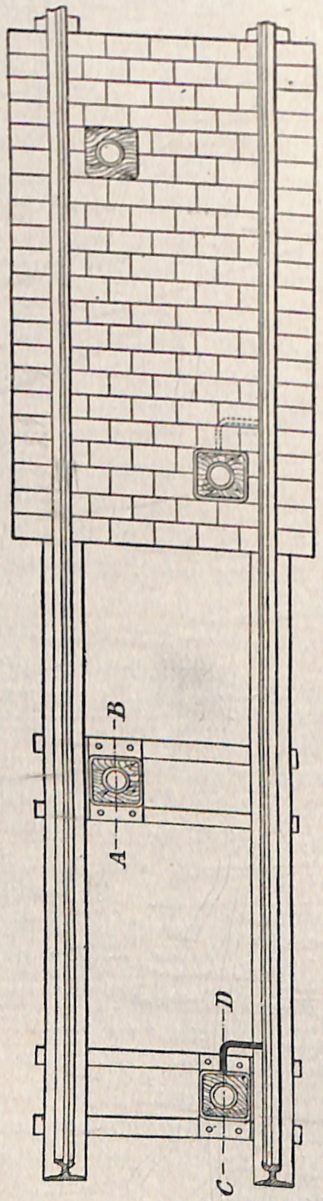


Fig. 203.—Thomson-Houston System—Plan of Track

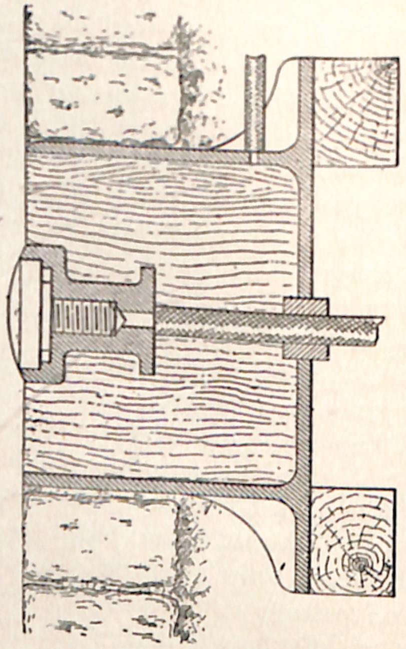


Fig. 205.—Section of Contact-stud at C D

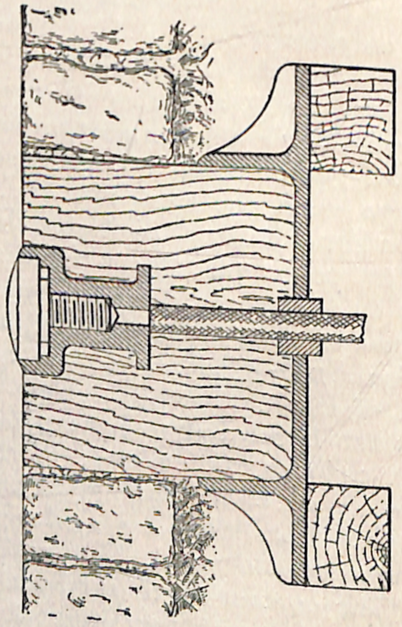


Fig. 204.—Section of Contact-stud at A B

the coil C_1, which attracts the armature D_1, which consists of an iron bar with three carbon contacts electrically connected to it. These carbon contacts are pressed against the three copper contacts of the electromagnetic switch. This enables the current from the main feeder to pass through the armature D, and the three contacts above referred to, to the high-tension

studs B_1 and B_2, from which it is collected by the skate F, and conveyed thence to the motors. From the motors it passes through skate E to the low-tension stud A_1, thence through coil C_1 to the rail. While the controller is on the first notch, and the switch K closed, the current from the motors divides, part of it passing through the storage battery to earth and part through the coil C_1. This arrangement keeps the storage battery automatically charged.

The next movement of the controller opens switch K and allows all the current to pass through the coil C_1. The skate will reach low-tension contact A before it has left A_1. The current from the motors then divides, part of it flowing through C_1 and part through C. This closes both switches D and D_1, so that high-tension contacts B, B_1, and B_2 are all alive at the same time, and it will be noted that the high-tension contact B is energized before the skate F comes in contact with it, which adds greatly to the certainty of an

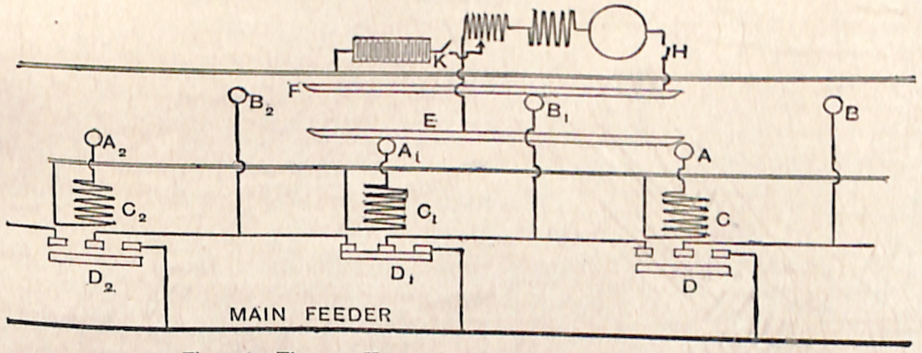


Fig. 206.—Thomson-Houston System—Diagram of Connections

electric contact being made. As soon as the skate E leaves the stud A_1 the current ceases to flow through the coil C_1, and the armature D_1 falls by gravity.

The switch is so designed that, should any current be flowing through the switch when the armature D_1 falls, a magnetic blow-out extinguishes the arc without damage to the contacts. It would be impossible for a leakage current to hold the switch C_1 closed, as, in order to do so, it would have to pass from the high-tension contact B_1 to the low-tension contact A or A_1, and the low-tension contacts are provided with a metallic shield, already described, which would short-circuit any leakage current to the rail, the iron case above referred to being securely connected to the rail.

The distance between the studs B_1 and A_1 is considerable. The only possibility of the high-tension studs being left alive is that of armatures D_1, D_2, and D_3 failing to fall, owing to some mechanical obstruction. It would, of course, be possible to provide the car with a short-circuiting skate to guard against this somewhat remote chance, but it does not appear to have been done.

The switches are arranged in groups located in watertight chambers beneath the surface of the road. It will be noted that the high-tension contact-studs are very close to the rail, the distance being about 1 foot. This is so close that a leakage current might in bad weather be quite a serious item. Also, that the distance between the low-tension studs and the iron box, which is connected to the rail, is very small, and that a connection established between these two would short-circuit the magnet coils and prevent the switches from acting. The difference of potential between these two points is, however, small, being only the fall of potential in the magnet coil itself, so this could not be a serious danger. The chief drawback to this system is the necessity for two sets of contact-studs.

Griffiths-Bedell System.—Fig. 207 shows a contact- and switch-plate as used at Lincoln, where the Griffiths-Bedell system is employed. The contact-plates are extremely simple, consisting of T-shaped pieces of cast iron, bedded with bitumen into a setting of solid granite. The stem of the contact projects downward into the outlet of the conduit. The lower end of the stem is slotted out, and in the fork so formed a simple sliding switch-piece of iron, the only moving part, is supported on a spring of phosphor-bronze wire, and slides between copper faces in the fork. At the lower end of the switch-piece a carbon contact is secured by copper clips, electrical connection with the stem being made by flexible copper leads.

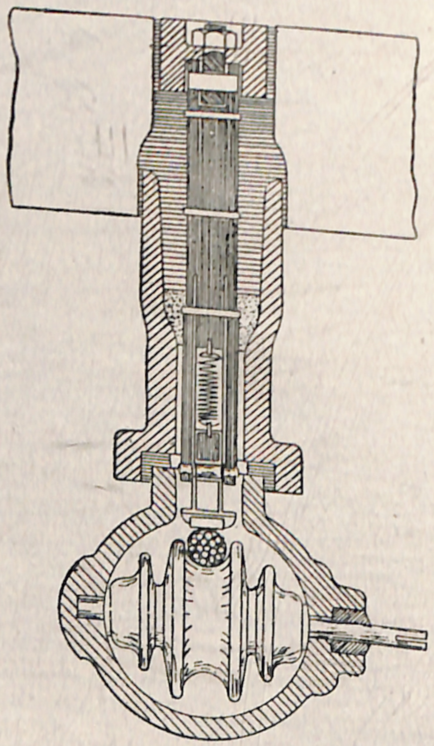


Fig. 207.—Griffiths-Bedell Stud

The mode of operation is as follows: When the magnet carried by the car passes over the contact-plate, the stem of the contact is magnetized, and the sliding-piece moves downward, partly through attraction, towards the cable beneath, and partly repelled by mutual magnetic action between itself and the iron of the fork. Thus the carbon block comes in contact with the cable, and the current passes to the head of the contact-plate, where it is received by the collecting-skate on the car. Directly the car has passed, and the contact-plate ceases to be magnetic, the pull of the spring withdraws the carbon block from the cable, and the plate is left absolutely dead.

Railless Overhead Electric Traction.—Engineers have, during the past few years, endeavoured to arrive at a system which combined the advantages of generating the electrical energy at a central station with the use of a vehicle moving freely on an ordinary road without the use of rails.

The result has been the adoption of the so-called Railless Trolley System, where a vehicle running on an ordinary road obtains its power from overhead wires in a similar manner to that adopted for an ordinary overhead trolley-wire car system with two trolley wires over each track, one for conveying the current to the cars and the other for conveying it back to the generating-station.

This is not really a tramway system at all, but that of a set of buses obtaining power from an overhead line.

The principal difficulty has been that of getting a suitable form of collector for the current from the trolley wires. There are two principal systems in use, viz.: The flexible system and the pole system. The flexible system has a collector in the form of a truck with four grooved wheels, two of which run on the positive and two on the negative wire. A heavy, swinging weight ensures a good contact between the wheels and the wires, and hooks are provided so as to prevent the truck from leaving the wires. The truck is drawn along by means of a cable attached to the car, and this cable can be lengthened or shortened by a special mechanism so as to suit the varying distance between the car and the overhead wires. On routes where there are only one pair of overhead wires erected a special detachable contact-box is fixed near the driver's seat, and two cars going in opposite directions exchange collectors when they meet.

In the pole system of connection the poles are similar to those used for ordinary electric cars with the overhead trolley system. The two poles are connected together at their lower ends so as to be always parallel to one another, and, being somewhat long and flexible, do not cause an excessive side-pressure on the trolley wires when the car is running at some distance to one side of them. The pole system has the advantage of being able to use the wires of an ordinary overhead electric tramway system, provided there be a "return" wire installed, either for both the tramway cars and the railless buses or for the buses only.

Railless buses can thus be run over the regular tramway routes when an extra service is required, or the trolley wires, erected at first for the railless buses only, can, later on, be used by the regular tramway cars after the rails have been laid, i.e. when the traffic has risen sufficiently to warrant the extra cost.

The Accumulator System.—The use of a battery from which to derive power to drive a car along rails is the oldest form of electric traction known; it did not, however, develop to any great extent, due to the difficulty of obtaining a good portable battery. Modern developments have, however, produced much more satisfactory accumulators for this purpose than were possible in the earlier days of electric traction. Mention may be made of the Edison and Wolff cells, which, from the point of view of durability, leave little to be desired. There are also a number of other cells of the older lead type, which can be satisfactorily used for traction work.

The great advantage of the accumulator system is that each of the cars is a separate and independent unit, and it is impossible that the system can ever fail as a whole (which does sometimes occur with all the other systems, due to a severe breakdown in the machinery at the power-station), or fail over a certain section (due to a short in the cable distribution-system, or some fault, either mechanical or electrical, in the overhead, underground, or surface-contact lines).

The use of accumulators on buses is a further development, which, at the present day, seems to have a more promising future than that on tramway cars, but this, like the railless trolley system, is not really a tramway system at all, and thus does not come within the scope of these articles.