Technical and Bibliographic Notes / Notes techniques et bibliographiques

The Institute has attempted to obtain the best original copy available for filming. Features of this copy which may be bibliographically unique, which may alter any of the images in the reproduction, or which may significantly change the usual method of filming are checked below.

L'Institut a microfilmé le meilleur exemplaire qu'il lui a été possible de se procurer. Les détails de cet exemplaire qui sont peut-être uniques du point de vue bibliographique, qui peuvent modifier une image reproduite, ou qui peuvent exiger une modification dans la méthode normale de filmage sont indiqués ci-dessous.

- [x] Coloured covers / Couverture de couleur
- [x] Covers damaged / Couverture endommagée
- [ ] Covers restored and/or laminated / Couverture restaurée et/ou pelliculée
- [ ] Cover title missing / Le titre de couverture manque
- [ ] Coloured maps / Cartes géographiques en couleur
- [ ] Coloured ink (i.e. other than blue or black) / Encre de couleur (i.e. autre que bleue ou noire)
- [ ] Coloured plates and/or illustrations / Planches et/ou illustrations en couleur
- [ ] Bound with other material / Relié avec d'autres documents
- [ ] Only edition available / Seule édition disponible
- [x] Tight binding may cause shadows or distortion along interior margin / La reliure serrée peut causer de l'ombre ou de la distorsion le long de la marge intérieure.
- [ ] Blank leaves added during restorations may appear within the text. Whenever possible, these have been omitted from filming / Il se peut que certaines pages blanches ajoutées lors d'une restauration apparaissent dans le texte, mais, lorsque cela était possible, ces pages n'ont pas été filmées.

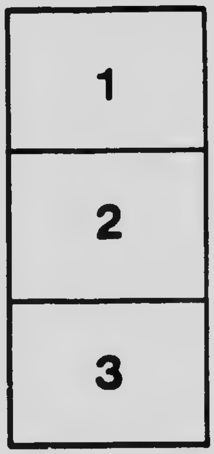
- [ ] Coloured pages / Pages de couleur
- [x] Pages damaged / Pages endommagées
- [ ] Pages restored and/or laminated / Pages restaurées et/ou pelliculées
- [x] Pages discoloured, stained or foxed / Pages décolorées, tachetées ou piquées
- [ ] Pages detached / Pages détachées
- [x] Showthrough / Transparence
- [ ] Quality of print varies / Qualité inégale de l'impression
- [ ] Includes supplementary material / Comprend du matériel supplémentaire
- [ ] Pages wholly or partially obscured by errata slips, tissues, etc., have been refilmed to ensure the best possible image / Les pages totalement ou partiellement obscurcies par un feuillet d'errata, une pelure, etc., ont été filmées à nouveau de façon à obtenir la meilleure image possible.
- [x] Opposing pages with varying colouration or discolourations are filmed twice to ensure the best possible image / Les pages s'opposant ayant des colorations variables ou des décolorations sont filmées deux fois afin d'obtenir la meilleure image possible.

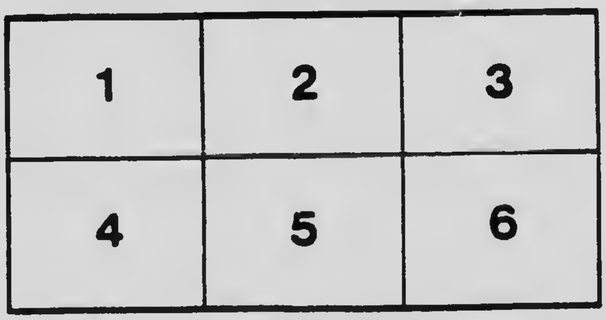
- [x] Additional comments / Commentaires supplémentaires: Pagination is as follows: p. [i]-ix, 1381-2214, i-xx. La pagination est comme suit: p. [i]-ix, 1381-2214, i-xx.

This item is filmed at the reduction ratio checked below / Ce document est filmé au taux de réduction indiqué ci-dessous.

10x 12x 14x 16x 18x 20x 22x 24x [x] 26x 28x 30x 32x


1
2
3


1
2
3


1
2
3
4
5
6

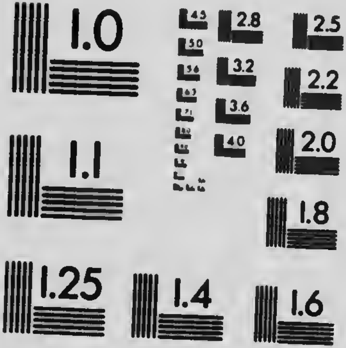
U

V

W

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



ELECTRICITY IN THE SERVICE OF MAN

OVERHEAD TROLLEY LINES ON A SUBURBAN ROAD

ELECTRICITY

IN THE

SERVICE OF MAN

A POPULAR AND PRACTICAL TREATISE
ON THE APPLICATIONS OF ELECTRICITY
TO MODERN LIFE

BY

R. MULLINEUX WALMSLEY

D.SC. (LOND.), F.R.S.E., M.I.E.E., etc.

Principal and Head of the Electrical Engineering Department of the Northampton
Polytechnic Institute, London; formerly Professor of Applied
Physics and Electrical Engineering in the
Heriot-Watt College, Edinburgh

WITH OVER 3,300 ILLUSTRATIONS

VOLUME II

TECHNOLOGY OF ELECTRICITY
Section III

CASSELL AND COMPANY, LTD
London, New York, Toronto and Melbourne
1921

CONTENTS

PART II

The Technology of Electricity *(continued)*

CHAPTER XIV

ELECTRIC TRACTION

CHAPTER XV

ELECTRIC RAILWAYS

CHAPTER XVI

TRACTION MOTORS AND LOCOMOTIVES

CHAPTER XVII

CONTROL OF THE ELECTRIC POWER IN TRACTION WORKING

CHAPTER XVIII

TRAIN RESISTANCE AND ELECTRIC TRACTION WORKING

CHAPTER XIX

ELECTRIC LIGHTING

CHAPTER XIX (*continued*)

ELECTRIC LIGHTING (*continued*)

CHAPTER XX

GLOW-LAMP DOMESTIC LIGHTING

CHAPTER XXI

ARC LAMPS

CHAPTER XXII

HIGH CANDLE-POWER AND SPECIAL LIGHTING

CHAPTER XXIII

ELECTRO-CHEMISTRY

CHAPTER XXIV

ELECTRO-THERMICS (i.)

CHAPTER XXV

ELECTRO-THERMICS (ii.)

CHAPTER XXVI

ELECTRICAL MEASUREMENTS IN POWER CIRCUITS

LIST OF FOLDING PLATES

ELECTRICITY

IN THE SERVICE OF MAN

PART II

The Technology of Electricity

CHAPTER XIV

ELECTRIC TRACTION

INTRODUCTION

THE problem of the application of electric power to the traction of vehicles, whether they be carts, carriages, tramcars or railway trains, is not the least fascinating of the problems which the harnessing of electricity in the service of man presents to us. Whether we consider the absence of everything which from the earliest dawn of civilisation has been regarded as a visible source of locomotion, or the mysterious methods of conveying the energy to the actual driving motors and the marvellous transformations which it there undergoes, we cannot but be lost in wonder at the paradoxes which we appear to meet on every side. Horses and other animals, and even the fierce fire of the steam locomotive, appeal to us as almost visible sources of energy or power, however little we may understand the modes of operation even there. But that a cold battery or a mere loose contact sliding on a rail or an overhead wire should be an important connecting link in the chain of transmission must excite the wonder of every thoughtful mind, and the wonder is not diminished by the miniature lightning flashes which are seen if the continuity of the circuit be momentarily broken at one of the sliding contacts.

The details of the generation and general handling of electric power having been dealt with in the preceding pages, it is only necessary now to consider the various methods of supplying the energy to the moving vehicles, be they tramcars, locomotives or railway trains, and the control and utilisation of the energy so supplied. But the subject, though summed up thus very briefly, is by no means a small one. It will be dealt with in the order named—that is, the methods of supplying the energy will be considered first, and afterwards its control and utilisation.

First, then, as to the practical methods by which energy may be supplied to moving vehicles, the problems involved are obviously very different in the two cases of (i.) those vehicles which have no reserve of energy on board, and which have therefore to pick up all the necessary energy whilst moving, and (ii.) those vehicles which, as yet, are not so widely used but which carry energy stored in some convenient form for transformation into electric energy as and when required. Again, in case (i.), which we propose to deal with first, we meet at once with two sets of conditions, fundamentally different from one another, which profoundly affect the solutions arrived at. The vehicles to be propelled may be required to run on the ordinary roads and streets which they must use in common with all sorts and conditions of traffic, or they may be confined to private roads (railways, etc.), from which such other traffic is, more or less rigorously, excluded. In the first case, it is obvious that the methods adopted must be such as not to endanger the lives of other users of the road; whilst in the second case this condition is absent, and greater freedom of choice results. Though some of the methods in the two cases have certain points in common, it will, on the whole, be more convenient to deal with them separately, and this chapter will, therefore, be devoted to the methods in use for supplying electric energy to tramcars and vehicles moving on public roads.

THE SUPPLY OF ENERGY TO TRAMCARS AND ROAD VEHICLES

I. SUMMARY OF METHODS

The energy required for the propulsion of the moving vehicle may, as explained above, either be picked up by that vehicle from moment to moment, as required, by establishing contact with stationary conductors conveniently placed for the purpose, or it may be carried on the vehicle itself and renewed at intervals, much in the way that a steam locomotive takes in stores of coal and water from time to time. In the former case, it may be referred to [illegible] *[illegible]ternal* or *picked-up* energy, and in the latter as being *internal* or *carried* [illegible].

The various methods may be further subdivided and tabulated as follows:

(A). —*Energy external or picked-up*:—

(i.) An insulated overhead conductor (or conductors) is carried above or at the side of the track, and contact is made by a rolling trolley wheel, or a sliding bow or some other device carried on the car. This method is often referred to as the **Overhead Trolley**, and may be used for vehicles other than tramcars, as in the "Railless Traction" system, where no tramway lines are laid on the road (ii.) Insulated conductors are fixed in a conduit, usually placed between the running rails, the top of the conduit being closed except for a narrow slot through which the shaft of a "plough" passes and makes the necessary contact. This method is usually referred to as the **Open or Slotted-conduit** method.

(iii.) Contact is made by a sliding skate or shoe, underneath the car, with a series of **surface contacts** placed at short intervals, usually between the rails, and connected as required to live conductors in *closed conduits* in the neighbourhood of the track.

(B).—*Energy internal, or carried:—*

(i.) **Secondary Battery** carried on the vehicle or car to be propelled.

(ii.) **Fuel-driven Engine** carried on the vehicle or car and used to drive a dynamo which supplies current directly to the car motors.

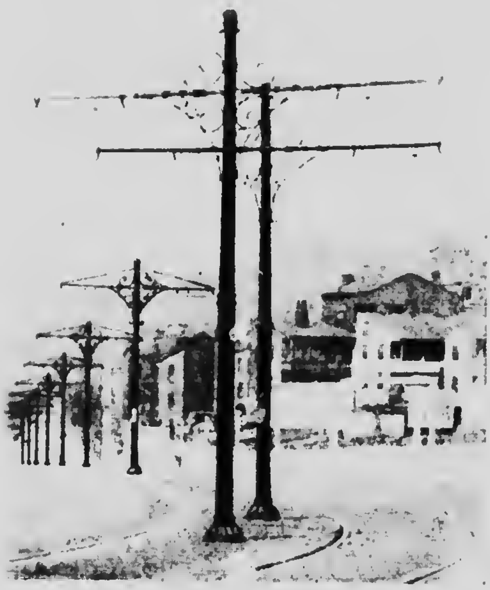
As regards the relative advantages and disadvantages of the "external" and "internal" methods of supplying energy, it may be pointed out that the latter, the "internal," does not require the erection and maintenance of expensive conductors along the whole of the route, and is independent of the length of that route, and even, where rails are not used, is not restricted to any particular route. Moreover, there is no ohmic loss of power on the line and no electrolytic troubles through using the rails and earth for the return circuit. On the other hand, the first cost and the depreciation charges for batteries are high, the inefficiency of the battery leads to a loss of energy, and the batteries at present available are heavy and add appreciably to the dead and unremunerative weight to be carried. In addition, valuable time is lost in changing the batteries as they become exhausted, and the cost of the equipment for such changes has to be incurred.

We propose now to deal, as succinctly as the subject allows, with the methods of conveying electric energy from a central generating station to the moving vehicles, and we shall take the methods summarised above in the order named, which is the order of importance as shown by their present utilisation.

II.—THE OVERHEAD TROLLEY SYSTEM

This system is placed first because, for reasons which will appear in the sequel, it easily distances all its rivals in the extent and importance of its applications to street tramway work and to interurban communication by means of light electric railways laid along ordinary country roads or otherwise. In this country the extent of its adoption with reference to other systems is overwhelming. Out of 180 such undertakings scheduled at the beginning of 1911 by *The Electrician* as owned in this country by municipalities and private companies, only eight were wholly or partially laid out on any of the other systems just referred to.

The Overhead Line.—In the overhead trolley system the problem is to suspend an insulated copper conductor (or conductors) of sufficient size to carry, without causing too great a loss by ohmic resistance, the currents required, and to provide the necessary appliances for conveying these currents into the moving vehicles. As a rule, though not necessarily, the vehicles are running on rails, and for tramway work the most convenient position for the insulated conductor is over the middle of the track, but it is possible to vary this position if desirable. In the so-called "trackless trolley" systems, where the vehicles run with ordinary wheels on ordinary roads, the trolley wire, as it is called, is usually erected at the side of the road. The conductors employed being, as a rule, of copper, from ¼ to nearly ½ an inch in diameter, or their equivalent, the weight to be supported is much heavier than in the case of overhead telegraph or telephone wires, and the additional condition of providing a continuous contact for the moving vehicles still further modifies the methods of suspension.



[illegible] Centre-pole Construction.

The main supports used for the overhead conductors may, for convenience, be classified as follows:

(i.) *Brackets* carried on posts or poles erected either (*a*) in the centre of the roadway, or (*b*) at the side of the road.

(ii.) *Span wires*, stretched across the road, and supported either by (*a*) side posts, or (*b*) from rosettes fixed in the walls of the adjacent buildings.

The bracket form of suspension is the most sightly, and lends itself, if desired in residential districts, to some attempt at decorative effect. The brackets are usually supported on poles, which may be of wood or of tubular iron, either cast or wrought. The iron is the neater of the two, but in most cases is the more costly for initial outlay. The æsthetic objection to the whole system that it ruins the amenities of the road by the erection of unsightly supports is partly met by designing these supports with some regard to artistic considerations, as appears in the frontispiece. This view represents a suburban road, but is reproduced from *The Electric Railway Journal* of New York. Another example of centre pole construction is given in Fig. 1,441, which represents a road in an American city, the poles used being the tubular poles of the Electric Railway Equipment Company, of Cincinnati. In this case the brackets are relatively much longer than in the frontispiece, the reason being that, as will be seen on close inspection, each bracket supports two trolley wires instead of one. These wires carry two of the phases of a three phase system instead of the single conductor for continuous currents with rail return circuit. It may be noticed that the "hangers" used are of the type illustrated later in Fig. 1,475.

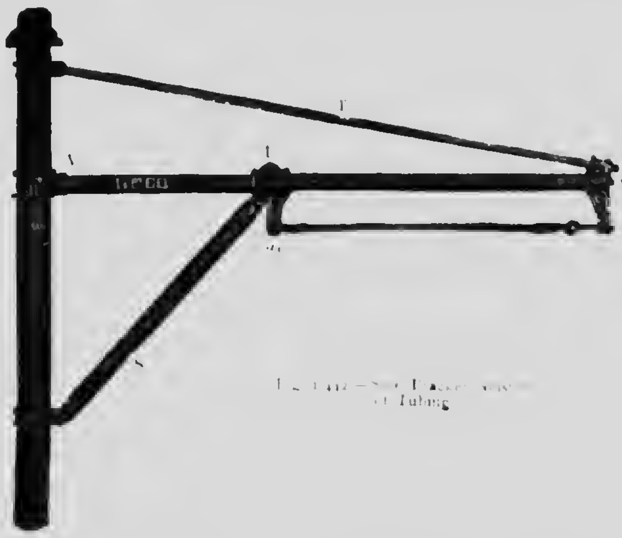


Fig. 1,442.—Side Bracket made of Tubing.

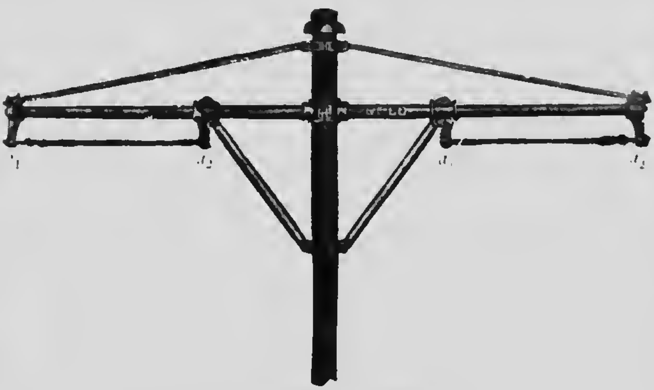


Fig. 1,443.—Central Pole and Arm.

The mechanically necessary parts of all such brackets are shown in a much cruder form in Figs. 1,442 and 1,443, of which the former is for use at the side of the road or track, and the latter is for use in the centre of the road where two tracks, one on either side, have to be provided with separate trolley wires.

Only the tops of the poles are shown, for the space available does not allow the details of methods of erecting the poles to be described.

In Fig. 1,442 a tubular arm A A, of wrought-iron or steel, 1½ or 2 inches in diameter and of a convenient length, the standard length being 9 feet, fits into a socket in a clamp, which can be attached tightly to the pole. At the outer end of the arm there is a metal fitment, which receives one end of the tie rod T, the other end of which is fixed to a clamp attached to the pole at a convenient distance above the arm-clamp. A sleeve L, sliding on the arm, carries the upper end of the hollow strut S, whose lower end is carried by a third clamp attached to the pole. The apparatus, to be described presently, which is to carry and insulate the trolley wire, is supported between the two short vertical arms a_1, a_2, which are in one piece with the strut sleeve and the end fitment respectively.

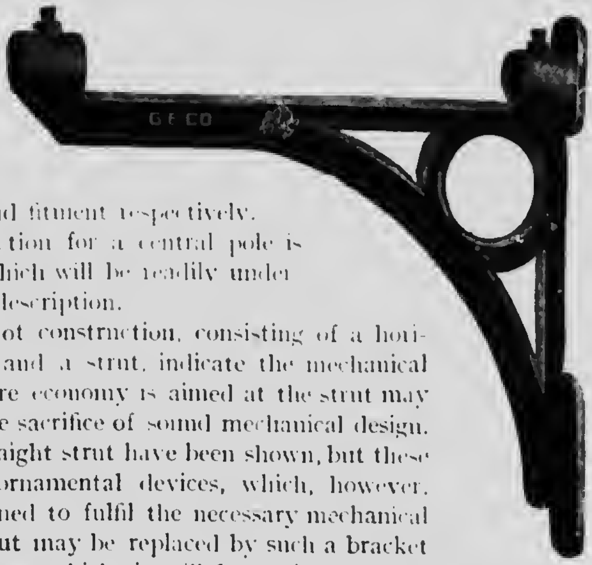


Fig. 1,444. Cast-iron Pole Bracket.

The similar construction for a central pole is shown in Fig. 1,443, which will be readily understood without further description.

The above method of construction, consisting of a horizontal arm, a tie rod and a strut, indicate the mechanical necessities, though where economy is aimed at the strut may be dispensed with at the sacrifice of sound mechanical design. A straight tie and a straight strut have been shown, but these may be replaced by ornamental devices, which, however, should always be designed to fulfil the necessary mechanical function. Thus the strut may be replaced by such a bracket as is shown in Fig. 1,444, which, it will be noticed, carries two sleeves for the insertion of the horizontal arm. Similarly the straight tie rod can be broken up into curved shapes. On all these points further reference may be made to the frontispiece and Fig. 1,441.

In the side-post and span-wire method of support the necessary and properly designed insulators are either hung from a stranded steel cable or wire, either insulated or uninsulated, which is made fast to eye bolts inserted in the walls of buildings on the sides of the road, or otherwise supported, say, from two posts opposite to one another on either side of the roadway, the necessary devices being simply strung across the roadway between the supports at the side. Theoretically, support might be provided, as mentioned, by walls, houses, or other erections at the sides of the road; but it is difficult and often impossible to obtain the necessary permission of the owners, and there is always the contingency that a suitable pair of supports may not be existing where they are particularly required. It makes for simplicity and convenience to erect the necessary poles as part of the plan of construction.

An example of the span wires being suspended from posts on either side of the road is given in Fig. 1,445, which again is a view of the use of the tubular posts of the Electric Railway Equipment Company in an American city. Here, as in Fig. 1,441, there are two trolley wires over each track.

One of the advantages of this method is that it leaves the surface of the road clear of obstructions which might interfere with other traffic, and

Fig. 1,445.—Trolley Wires Supported by Side Poles and Span Wires.

is more adaptable to varying conditions than the side-pole and bracket method, besides being mechanically preferable to the latter when the distance of the track from the kerb would necessitate an abnormally long overhanging bracket. The relative sightliness of the two methods, or the actual sightliness of either is a subject we do not feel called upon to discuss here.

The necessary supports having been provided by one of the foregoing methods, there still remains a choice of methods by which the actual conductor itself may be supported and insulated. The wires may be gripped by "ears," as they are called, which are attached to insulators, or they may be gripped by "clips" carried by flexible wires, which in their turn are attached to an insulated steel wire (or wires) suspended at a higher level than the conductor. The second of these is known as the *catenary* method of suspension. The problem is to present a smooth, continuous surface for rubbing or rolling contact on the *under* side of the conductor, and at the same time to give some vertical flexibility to the conductor. The latter condition is secured without difficulty by the fact that the supports are necessarily at some distance apart, and that the conductor itself is fairly flexible. It is further obvious that every method used must be thoroughly sound from a mechanical point of view, because of the conditions of actual working. Turning now from the methods of support, we propose next to give some details of the conductor, and to work backwards from it to the supports we have described.

The Conductor. The most important factor in the whole design is obviously the wire itself, and in its simplest form this is of circular section. A wire with such a section can, however, not be so readily attached to the suspending ear as to fulfil the necessary conditions (i.) of presenting a smooth and uninterrupted under surface to the trolley wheel and, on the other hand, capable (ii.) of being gripped firmly by the suspending ear of one of the patterns illustrated later (Figs. 1,447 and 1,462). To fulfil the latter condition well it is obvious that the sides of the ear should pass below the horizontal diameter of the round wire, so as to grip on at least a part of the under surface of the cylindric wire. To obtain this mechanical support the circular cross-section is sometimes modified, and three of such modified sections are shown in Fig. 1,446, where also the circular section is shown at A. The section B is that of a conductor nearly circular, but with two longitudinal grooves at the upper part, into which the sides of the ear can enter with a firm supporting grip. At C the section is an elongated figure 8, the upper part of the section having the grooves not so deeply undercut as in B, the general effect of the undercutting being the same; whilst at D an entirely different method is adopted, for in this section the upper surface of a cylindrical wire has a deep channel running along its whole length. The channel has overhanging edges as shown, and these support the wire by means of a proper modification (Fig. 1,454) of the suspending ear.

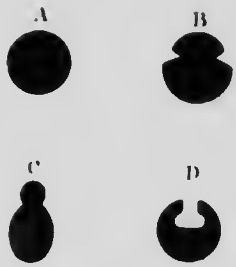


FIG. 1,446.—Cross-sections of Overhead Trolley Wires.

The material of the conductor is usually hard-drawn copper of high conductivity and of suitable cross-section for the particular work. Wires of aluminium and of copper with a steel core are also used. The area of the cross-section, of course, determines the conductivity, and therefore the C^2R heat loss, as well as the weight per mile, and through it the capital cost. The area most usually adopted in this country is that which is nearly equivalent to the area of a circular wire of No. 0 or No. 00 of the Imperial standard wire gauge (s.w.g.). For heavy work a gauge as large as that of No. 000 s.w.g. is sometimes used. Data regarding these three gauges as published by the British Insulated and Helsby Cables, Limited, who manufacture wires of the section shown in Fig. 1,446, are given in the following table:—

TABLE XXII.—DATA RELATING TO COPPER TROLLEY WIRE.

	No. [illegible]	No. [illegible]	No. [illegible]
Diameter of equivalent circular section (*inches*)	0·324	0·348	0·4[illegible]
Area of cross-section (*sq. ins.*) ..	0·0824[illegible]	0·0951[illegible]	0·1257
Resistance per mile at 60° F. (*ohms*)	0·5235	0·4538	[illegible]·3435
Weight per mile (*lbs.*)	1,677	1,933	2,558
Breaking tension (*lbs.*)	4435–4620	4900–5320	6[illegible]–6800
Breaking stress (*tons per sq. in.*) ..	24·25	23·25	22·5–24·[illegible]

The constancy of the cross section can be guaranteed within 2 per cent.

It has already been mentioned that the two chief methods of supporting the wires are (i.) by "insulated ears," and (ii.) by the "catenary" method. For street traction work the former is most widely adopted, whilst for railway work the second method is more generally used if the system be an overhead one. We shall therefore describe the "insulated ear" method in connection with traction on ordinary roads, and reserve the description of the "catenary" method until we deal with railway traction.

Fig. 1,447.—A Single "Straight Line" Ear.

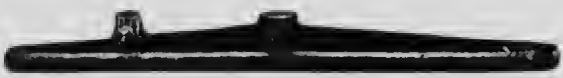


Fig. 1,448.—A Simple "Feeder" Ear.

"Insulated Ear" Suspension.

The particular fitting which grips the wire in the "insulated ear" method of suspension is technically known as an "ear." The general external appearance of these ears, many patterns of which have been devised, is shown in Figs. 1,447 to 1,449, which depict some of the ears manufactured by the British Insulated and Helsby Cables, Limited. The simplest form is the "straight line" ear of Fig. 1,447. It consists of a webbed length of metal as shown, the length varying from 9 to 24 inches, grooved on the long under surface as shown in subsequent figures, and carrying a tapped lug at the middle of its upper surface by which it can be screwed on to the end of a bolt which is usually of either ⅝ or ¾ inch diameter. In Fig. 1,448, which is an example of a "feeder" ear,

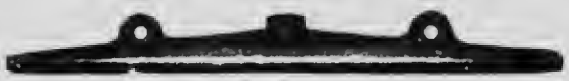


Fig. 1,449.—A "Double Anchor" Ear.

there is an additional lug cast on the upper web, to provide a clamp by which a conductor can be clamped to the ear and thus supply current to the trolley wire which it supports. The "double anchor" ear, shown in Fig. 1,449, has two "eyes" cast on its upper web, the object being to provide an attachment for stay wires for steadying the trolley wire in exposed positions and in going round curves; in these cases it is obvious that the ends of the stays attached to the eyes of the ear must be independently insulated.

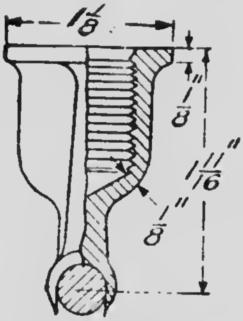


Fig. [illegible] View and Cross-section of an Ear for Soldering on a Round Trolley Wire.

The method of attachment of the wire to the ear is of great importance. For round wire the groove in the ear is supplied ready turned, and the wire is sweated in; but some more direct support than is given by the solder is obtained by bending the sides of the groove so as to curve round part of the under surface of the wire. A side view of an ear, partly in section at the bolt hole, is shown in Fig. 1,450 with a section of the trolley wire in position, but with the bottom edges of the groove not yet pressed inwards. These edges are finished to a knife-edge so that when turned in they shall cause the least possible interference with the cylindric surface of the wire and consequently with the under running of the trolley wheel

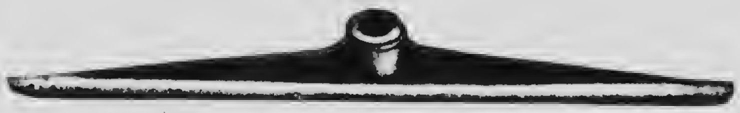


Fig. 1,451.—Another View of a "Straight Line" Ear.

A perspective view of this ear, which is manufactured by the Western Electric Company, is given in Fig. 1,451. The example shown is 15 inches long.

In some designs, as shown in Fig. 1,452, the edges of the groove are made still longer, so that the lips can approximately meet beneath the wire, in which case they can be used without solder.

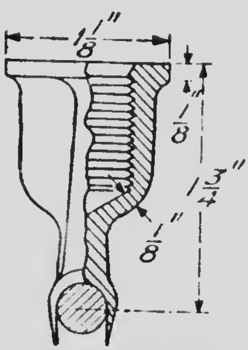


Fig. 1,452.—Ear Designed for Clinching a Round Trolley Wire.

For grooved wires the groove of the ear should obviously be designed to fit the special groove of the w[illegible] and a Western Electric Company's ear of this type, with the wire shown in cross-section in its place, is depicted in Fig. 1,453. These ears are sprung on the wire, which they fit accu

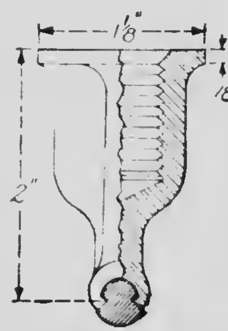


Fig. [illegible] Ear for Grooved Wire.

rately and are then usually soldered. The dimensions given in Figs. 1,450, 1,452 and 1,453 should be noted.

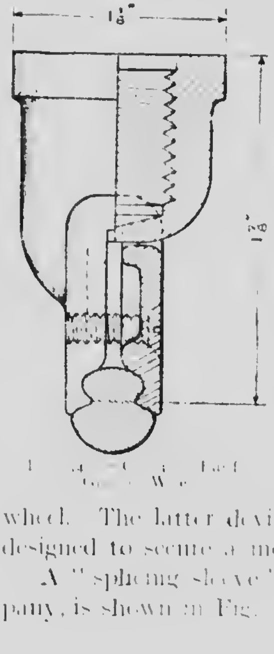
With "channelled" wire (*see* D, Fig. 1,446) the lower part of the ear is,

of course, modified with an expanding tongue, which can slide in the channel of the wire. The necessary modification is obvious, and is illustrated in Fig. 1,454, which gives an end view of the ear and shows also the under running trolley wheel when passing the ear; a side view is given in Fig. 1,455. The figures show how the contact of wheel and wire at the ear is absolutely identical with that at any other part of the wire, thus ensuring an absence of bumping and arcing, with a corresponding decrease in the cost of maintenance.

Fig. 1,456.—C[illegible] Ear with M[illegible] Jaws [illegible] Wire.

F[illegible] 1,457.—[illegible]

Other devices are also employed to ensure the firm attachment of the wire to the ear. One of these is shown in perspective in Fig. 1,456. It is a Western Electric Company's design, and consists of two drop forged steel jaws hinged together with a steel pin. The lower ends of the jaws are forced towards one another by the clamping nut, so that the turning of the hexagonal nut seen in the figure tightens the clutch of the ear on the wire. The ear is 3 inches long and 2 inches high, and the hollow [illegible] is tapped to take a ⅝-inch bolt. The modification of this ear when it is [illegible]ovided with a socket to receive a feeding wire is shown in Fig. 1,457. Part of the outfit consists of a special double spanner, which fits the two hexagonal sizes of nuts used in the feeder ear.



F[illegible] 1,458.—C[illegible] Ear f[illegible] Grooved Wire.

Still another method of clamping the jaws of an ear on to a grooved wire is shown in Fig. 1,458, which represents partly in section a form of ear made by the A. and J. M. Anderson Manufacturing Company, of Boston. The drawing is partly in section, and shows clearly the details of the design.

Before leaving the subject of ears, a word may be said on the method of splicing the end of one length of wire to the beginning of the next. This is effected by using either a splicing sleeve or a specially modified splicing ear. The former has the disadvantage that it may materially increase the diameter of the wire at the splice, and thus interfere with the smooth running of the trolley wheel. The latter device is more frequently used, especially as it can be designed to secure a more reliable mechanical result.

A "splicing sleeve" or "splicer," as made by the Ohio Brass Company, is shown in Fig. 1,459, the view being partly in section to show the method of clamping the end of each trolley wire with three steel set screws. The under side of the splicer is like the under side of an ear, but whilst the lips at the end are ground to a knife edge they are thicker towards the centre so as to give a firmer grip, and there is a depression under each set screw to give greater holding power. The hole at the centre is to show

Fig. 1,459.—Trolley Wire Splicer.

when the wire is inserted to the proper distance, and there is a barrier to prevent it being inserted too far. The length of the splicer is 20 inches, and the weight is so distributed that it is not top heavy.

A form of splicer which gives a grip on the ends of the wires mechanically better is shown in section in Fig. 1,460. Externally, the splicer has the

Fig. 1,460.—[illegible] Wire [illegible]

form of two cones of gradual taper placed base to base and the trolley wires project into a coned internal space in which they are gripped by tapered steel dogs, as shown. These dogs are slid in through the central hole after the wires are in place. No soldering is necessary.

Of the numerous "splicing ears" which have been designed, space will only allow reference to two, which are shown in Figs. 1,461 and 1,462, which depict ears manufactured by the British Insulated and Helsby Cables, Limited. In each case the ear is designed for round wire, and the method adopted can be readily made out from the figures. In Fig. 1,461 which shows a 15-inch ear, the end of the wire after being carried along some 6 inches on the lower groove is turned vertically upwards and bent backwards horizontally on the similar groove on the top of the wire, the whole being then carefully soldered. It will be noted that the full tension of the line has to be countered by the soldered hook thus made, a result which cannot be regarded as altogether reliable. Splicing ears, with firmer clampings of the end of the wire, have therefore been designed, and one of these is shown in Fig. 1,462, which again is intended for round wire, and is also 15 inches long. A hooked-shaped groove formed in the material of the ear is closed by the clamping plate, seen on the right, which prevents the wire from slipping and is held tightly in position by no fewer than five screws. Another advantage of the

Fig. 1,461.—A Simple Form of [illegible]

Fig. 1,462.—Splicing [illegible]

design is that the surface under the ear, when the work has been properly finished, presents greater continuity to the trolley wheel than that resulting from the use of the ear shown in Fig. 1,461. Proper bending tools are supplied to bend the wire so that it shall fit the groove accurately.

Ear Bolts.—The bolts from which the ears just described are suspended are usually insulated from the other parts of the fitment which supports them, though that fitment as a whole is, as a rule, itself insulated. Two general methods are in use. In one the stem and head of the bolt are covered with insulating material, and it is then slipped into its place in the fitment, but can be taken out again and replaced by another insulated bolt if and when required. In the other, the stem and head of the bolt

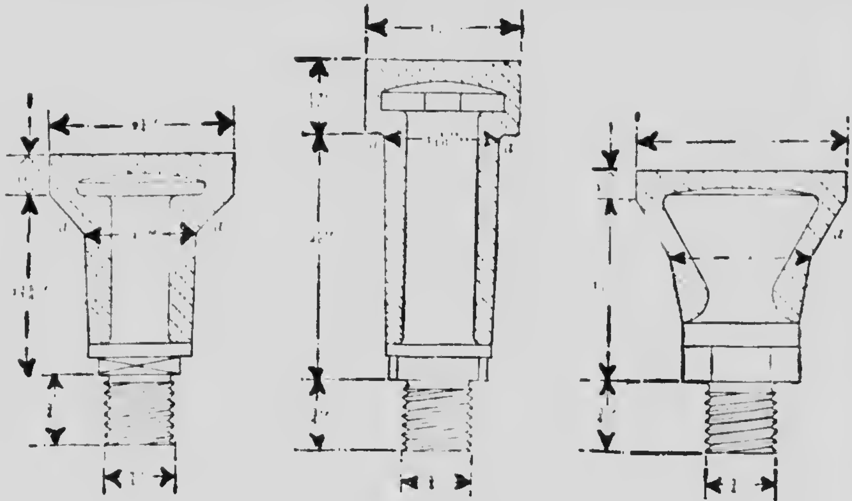


Fig. 1,463. Fig. 1,464. Fig. 1,465.

Different Patterns of Ear Bolts.

cannot be detached from the fitment, for they are permanently imbedded in insulating material forming part of the fitment. Three removable bolts, as made by the British Insulated and Helsby Cables, Ltd., are shown in Figs. 1,463 to 1,465, the shaded part in each figure denoting the insulating material. Dimensions for a particular size are given in each case but several sizes are manufactured.

The insulating material used must fulfil several conditions. It must be capable of being moulded on the bolt to the required shape, but should not subsequently soften appreciably at any temperature likely to be reached in practice. It should also be a good insulator, and capable of standing an electric pressure of 600 volts without appreciable leakage. The materials available which fulfil these and other conditions are mechanically incapable of sustaining a tensional stress, and therefore if the apparatus in which they are used is to be called upon to sustain heavy tensional forces, this apparatus must be so designed that the insulating material whilst transmitting these forces is put under a compressive and not a tensile stress. That this result is attained in the bolts shown in Figs. 1,463 to 1,465 will be realised on inspection of Fig. 1,466, which shows a "straight line hanger" intended to hold one of these bolts. By taking off the screwed cap the bolt can be inserted, so that the coned or shouldered outer surface of the insulating material rests firmly against the inner surface of the metal of the hanger. Thus the shoulder (Fig. 1,464) or cones (Figs. 1,463 and 1,465) at *a a* are supported from below, and the vertical pull on the bolt due to the weight of the trolley wire causes a compressive stress on the insulating material in its transmission to the suspending device which supports the hanger. How this and other hangers are supported is dealt with elsewhere.

Fig. 1,466.—A Straight Line Hanger.

The above will be made clearer by an inspection of Fig. 1,467, which shows, partly in section, a similar hanger, as made by the Western Elec-

[illegible]

ric Company. The insulated bolt used is practically identical with Fig. 1,464. The outer surface of the ins[illegible] sleeve on the bolt and the inner surface of the outer shield, are both slightly tapered. Thus at *a* the diameter is [illegible] in., and at *b* [illegible] in. The way in which the bolt head bears upon a shoulder in the cover should be noted. The metal used is malleable cast-iron, and the insulating material between the stud cap of the bolt and the body casting will stand a dead load of nearly 6 tons without crushing. An external view of the hanger is given in Fig. 1,468.

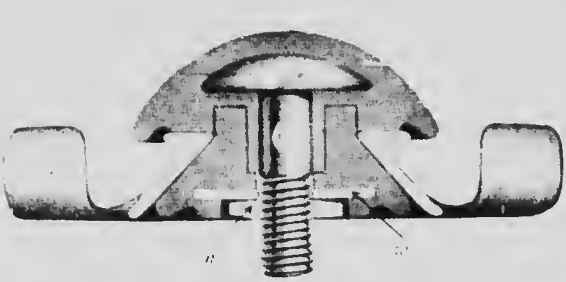
The other form of suspension, in which the bolt and cap with the insulating material between are all in one piece and from which the bolt cannot be removed, is shown in Fig. 1,469, which, after what has been already said, scarcely needs any further description. The dark, shaded part represents the insulating material which has been moulded *in situ*.

[illegible]

As another example of this form of hanger, Fig. 1,470 shows the pattern evolved by the A. and J. M. Anderson Manufacturing Company. In this pattern the outer shell with the curved outrigger ears is also made of malleable iron and is in one piece. The steel stud, which is insulated from the shell by what is known as "Aetna" insulating material, is drop forged, and the overhanging skirt on the shell is designed to shield the insulating material from mechanical injury as well as acting as a rain-guard.

[illegible]

An intermediate form of hanger in which the external cap is moulded round the bolt head is shown in Fig. 1,471, which is a section of a hanger of the Ohio Brass Company. The moulded insulation on the head of the bolt is extended down the bolt shaft. Insulating material is also moulded into a cone-shaped metal body with outrigged ears, which forms the lower part of the hanger, and this insulation is corrugated on the lower surface to diminish the surface leakage. A washer *a* is bedded in it, and the two parts are clamped together by the lock nut *n*.



[illegible]—Hanger with Bolt Embedded in Cap.

The hangers so far shown have outrigged ears and grooves for suspension from a span wire, as shown in Fig. 1,472, a method of suspension which is very convenient for straight lines, as the hangers can be rapidly placed on the supporting wires. The hanger shown is similar to but not quite the same as that just illustrated in Fig. 1,471.

Fig. 1,472.—Hanger and Ear Suspended from Span Wire.

For curves, single or double, the outrigged ears are replaced by curved arms with "eyes" at their outer ends to which stay wires can be attached, these wires being made fast at their other ends to supports so placed that the necessary mechanical forces on the trolley wire can be counterbalanced. These are illustrated in the "single pull-off" or "single curve suspension" of Fig. 1,473. Another form is the "double pull-off" or "double curve suspension" shown in Fig. 1,474.

Fig. 1,473.—Single-curve Suspension with Embedded and Insulated Bolt.

Fig. 1,474.—Double-curve Suspension with Embedded and Insulated Bolt.

A single pull-off suspension with the hanger and the ear for the trolley wire in position is shown in Fig. 1,475. The pattern is one designed by the General Electric Company, of Schenectady, and the hanger is shown in section from which it will be seen that the thickness of insulation between the head of the bolt and the cap is not great. The insulator used at this place, however, is sheet mica, the moulded insulation occupying a much safer position under the cap. The form of the opposed surfaces at the top of the bolt should be noted, as they are specially

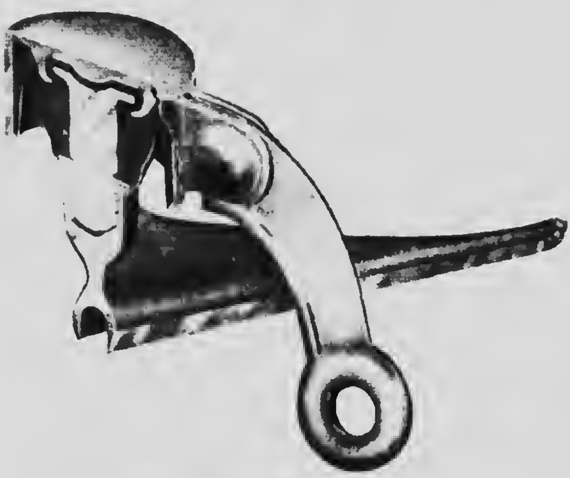


Fig. 1,475.—Single-curve Suspension.

designed to remove the mechanical strain from the moulded insulating compound.

An entirely different form of "hanger," in which the insulating material is porcelain, is depicted in Figs. 1,476 and 1,477, which show the separate parts (Fig. 1,476) and the complete hanger (Fig. 1,477) with the stranded suspension cable in position. This pattern of hanger is made by the T. C. White Electrical Supply Company, of St. Louis, and consists of three parts, (1) the porcelain body A, the details of the design of which can be readily made out; (2) the sherardised malleable iron yoke Y, which, when the parts are assembled and the hanger suspended, is firmly held in its place by the cable, which is in tension; and (3) the bolt B, with its square head, which fits into the recess in the upper part of the porcelain and is

Fig. 1476.

Fig. 1477.

A Porcelain Hanger.

thus prevented from rotating when the nut and ear for the trolley wire are screwed home. It is claimed that this form of hanger is easier to hang and align than the more usual form, and that it has a longer life. On the other hand it is obvious that whilst the insulation resistance through the material is very high, the resistance in wet weather to surface leakage between the yoke and the head of the bolt must be low. It would therefore appear to be specially necessary, in using these hangers, to insulate the suspending cable by some type of strain insulator described later.

Frogs at Crossings and Junctions.—The cases of crossing routes and junctions have still to be considered. Where routes cross in overhead trolley systems the same electrical difficulties do not arise as in slotted-conduit systems, where there are both + and − conductors (*see* pages 1426 *et seq.*). The overhead trolley wires of any single insulated conductor system are at crossing points usually at the same potential and need not be insulated from one another. All that is required is to ensure that the trolley wheel shall follow the proper route, and not be deflected into the wrong one. This is, of course, the more difficult the more acute the angle at which the crossing takes place, and to illustrate the difficulty there is shown, in Figs. 1478 and 1479, a 15° fixed crossing, or frog, as it is sometimes called. The frog as seen from above is shown in Fig. 1478, and Fig. 1479 shows it as seen from below. The trolley wires for the two routes pass over the frog without being cut, and are clamped by the nuts at the four corners. Where they run into the grooves the

Fig. 1478.

Fig. 1479.

[illegible]

latter are tapered to a knife edge to ensure the smooth running of the trolley wheel. The ribs on the under surface are considered sufficient to ensure that the trolley wheel shall not go astray, and it should be noted that there are downward projecting flanges to keep the wheel from running right off at the actual crossing-over points. As additional precaution it is usually so arranged that the relative positions of trolley wheel and car are such that the former is being pulled over on to the proper route. The whole frog has, of course, to be suspended from insulated wires or insulators.

Fig. 1480.

Fig. 1481.

[illegible]

Where there is a junction of routes, frogs constructed on the same general principle can be designed with the important modification that one of the wires must necessarily be terminated at the frog. Probably the simplest form of frog for a junction is that shown in Figs. 1480 and 1481, which is a frog manufactured by the Westinghouse Company. In this case Fig. 1,480 shows the under surface, and the projecting semi-cylinders on which the trolley wheels are to run in passing. One route is straight through, and the other comes on at an acute angle, and it is obvious that in passing from the straight to the side the wheel must be pulled well over. Fig. 1,481 shows the upper surface and the arrangements for clamping the straight-through wire, and for clamping and terminating the side route wire.

It is generally considered safer to employ a frog with a movable tongue ordinarily set for the run-through which is most used, but capable of being held over for the other route whilst the trolley wheel passes. Such a "mechanical frog" is shown in Figs. 1,482 and 1,483, the top figure showing the upper surface and the bottom figure the under surface. The details of the arrangement will be apparent on inspection, and it need only be added that the switch is worked from the ground level by means of a rope passing over pulleys and attached to the "eye" on the arm of the bell crank lever, to which the spring s is not attached. In this case the spring is arranged and set to hold the switch hard over for the straight through position, in which it is seen in the top figure. With this frog the wires for each of the three "ways" are terminated at the frog.

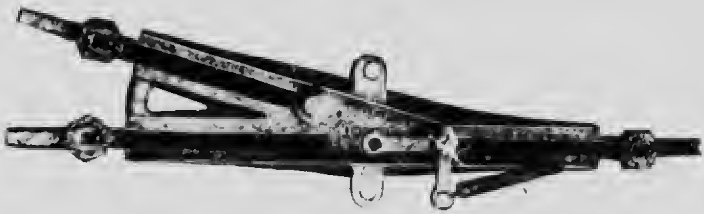


Fig. 1,482.

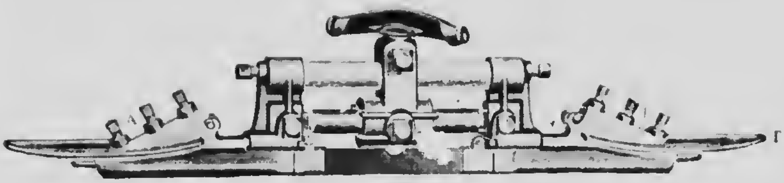
Fig. 1,483.
Frog with Movable Tongue

Insulated Crossovers. Another case which requires a specially constructed fitting is where one route crosses another and it is necessary for electrical reasons that the two trolley wires should not come into electrical contact. It would, obviously, be possible to design a fitting in which, the two trolley wires being cut, the trolley line on each side should terminate at the fitting and be made fast to it. If, however, a fitting be designed for which the trolley wires need not be cut, the mechanical conditions will be less exacting, and a lighter construction will suffice.

Such a fitting, designed and manufactured by the Ohio Brass Company, is shown as seen from below in perspective in Fig. 1,484. The trolley wires are received on the top of the curved bronze tips *tt*, which are quite short. The other sections of the runners along which the trolley wheel travels are of white bone fibre, and there is a short break at the crossing point where there is only a cone projection. The trolley wire from left to right, after passing under clip guides, runs along the top of the wooden hickory beam, which is the body of the fitting, and which has been impregnated with insulating varnish. By withdrawing a bolt the other runway from front to back of the diagram can be detached, whilst the other trolley wire is run over it and clamped, after which the runway can be replaced in the fitting, the two wires being separated from one another by the hickory beam.

[illegible] Trolley Wire

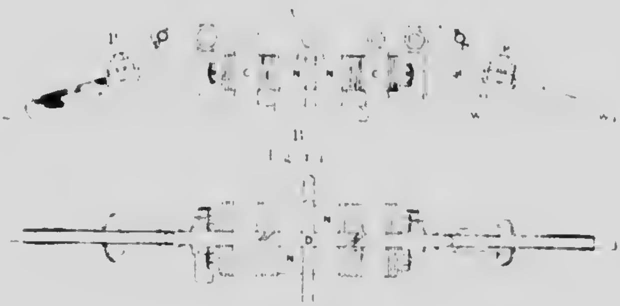
Section Insulators.—Other points at which special suspension ears are required are at the ends of the various electrical sections of the trolley wire. It will be readily understood that where the length of the system runs into miles it is very desirable to be able to disconnect one portion of the trolley wire from another, either for testing purposes or in the event of a broken wire or other emergency. The continuity of the path for the trolley wheel must, however, be maintained. The conditions are satisfied by placing at certain distances apart a form of suspension known as a section insulator. By the courtesy of Messrs. Watlington and Co., of



[illegible]

London, the author is enabled to illustrate in Figure 485 a section insulator as used in America. As electrical continuity [illegible] be broken the trolley wire must be cut and the fitting must act as a terminal ear for the wires running in both directions from it. In design, therefore, the insulator consists of two such terminal ears A and B, electrically insulated from one another but mechanically tied together with the two trolley wires in alignment, and with a short piece of insulating material *m*, in this case made of hardwood, inserted between the ears to provide the mechanically continuous path for the under-running trolley wheel. The pieces, by which the whole apparatus is suspended from an overhead cable or a bracket, is also insulated from the two ears, and the interconnecting bolts which give the necessary mechanical strength pass through insulating bushings and are covered with insulating sleeves s s. The method of securing the cut trolley wire should be noted. The wire coming from the right-hand side passes under the loose tongue *t*, which bears against the stiff tongue T and is held firmly in place by the three bolts *b b b*, the lower ends of which bear on the upper surface of *t* and not directly on the wire; the free end of the wire passes out at the heel *h* and can be bent over in the form of a hook, which will tend to prevent slip.

Another pattern of section insulator, as made by The British Insulated and Helsby Cables, Ltd., is shown in Figs. 1,486 to 1,488, of which Fig. 1,486 is a side view, Fig. 1,487 a vertical section on the line A B (Fig. 1,486), and Fig. 1,488 a view from underneath. In this case the central insulator N N has the peculiar cross-section shown in Fig. 1,487, the lower part providing



[illegible]

[illegible]

the mechanical non-conducting bridge D necessary to carry the trolley wheel across from one terminal ear to the other. The position of the longitudinal bolts as they pass through the insulating material can be readily made out, and these bolts are, of course, heavily bushed with insulation where they pass at C C through the metal of the ears. The wire W W is in this case bent quite round and clamped by means of the screws P P between two well-designed gripping surfaces. The overall length of the insulator is 21 inches, and the vertical height 4 inches.

Strain Insulators.—Another type of insulator is much more frequently required in overhead work, namely, one which can be interposed in a suspending cable or a stay wire so that the metal nearer the live trolley wire may be fairly well insulated already, whatever further insulation may be used for the suspending bolts, etc. The problem usually is to insul[illegible] from one another two ring bolts placed in line so that the combi[illegible] n may be capable of transmitting a considerable mechanical force w[illegible] being distorted or broken; it must also be capable of being exposed to the weather without deterioration, and must not be too costly. Unfortunately the available insulating materials, as has already been pointed out, have very low tensile strength. The solution is provided by various patterns of "strain" insulators which have been designed, and which follow the rule adopted for insulating the bolts of cars, namely, that the material is subjected, when the insulator is in use, to a compressive and not a tensile stress.

One of these strain insulators, as made by the Anderson Manufacturing Company, is shown in Fig. 1,489 and in section in Fig. 1,490. The two ring bolts B_1 and B_2, made of drop-forged steel which have their ends expanded into two dome-shaped discs D_1 and D_2, as shown, are placed in line and surrounded by a steel shell or ring S S, thin sheets of mica being placed between the discs. Soft insulating material, which afterwards hardens, is moulded in between the metal parts, and eventually when hardened holds them in the relative positions shown. The ring bolts are obviously insulated from one another, and if a considerable tensile force tends to pull them apart, the stress in the insulating material is chiefly taken up as a compressive stress between the domes D_1 and D_2 and the shell S S, the actual direct tensile stress between D_1 and D_2 across the intervening space being comparatively small. Thus a considerably greater pull than could be transmitted directly from D_1 to D_2 without either rupturing the material or pulling the discs away from it can be safely transmitted from the ring B_1 to the ring B_2. The mica sheet is to insulate the two discs from one another if by any chance the insulator is so distorted that they would be in danger of making metallic contact with one another.

FIG. 1,489.—Anderson Strain Insulator.

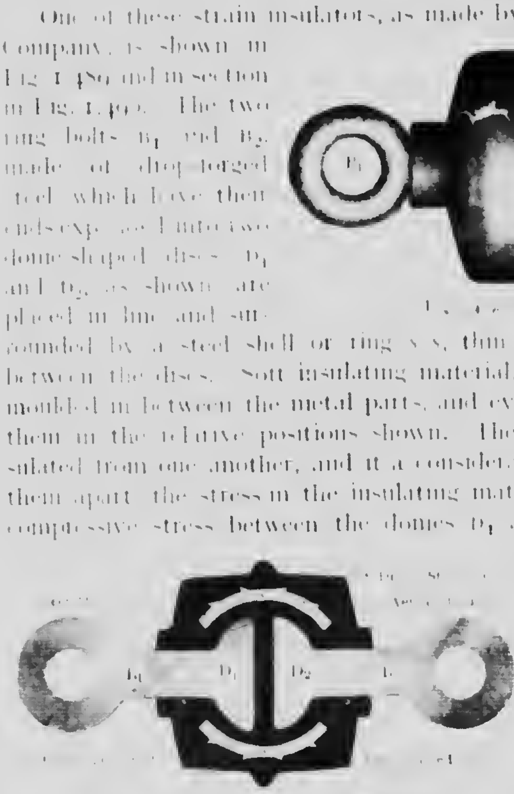
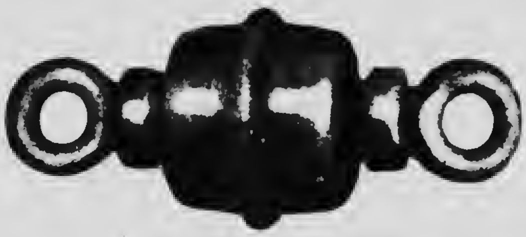


FIG. 1,490.—Section of Anderson Strain Insulator.

Another pattern of strain insulator, as made by The British Insulated and Helsby Cables, Ltd., of Prescot, is shown complete in Fig. 1,491, and in section in Fig. 1,492. In Fig. 1,492 the lightly shaded parts indicate insulating material, and the dark or black parts the metal of the bolts and the strengthening ring corresponding to S S of Fig. 1,490. The principles utilised are the same as in the preceding case, the differences being in the actual materials used, and in the shape and disposition of the parts to fulfil the mechanical and electrical requirements. The reader should compare Figs. 1,400 and 1,402 carefully, and endeavour to decide which best fulfils the conditions apart from the relative merits of the insulating materials. The mica sheet is not used in Fig. 1,402.



[illegible] Strain [illegible]

In some patterns of this type of strain insulator, the only insulating material relied upon for electrical separation is sheet mica or micanite, though some moulded insulation may also be used in positions where there is little tendency to direct conduction. A section of one of these, in which sheet mica is used is depicted in Fig. 1,403, which shows in section the "Giant" Strain Insulator made by the General Electric Company, of Schenectady. The figure shows the layer of mica relied upon to insulate against direct conduction. The exposed part is, in the finished insulator, protected from the weather by a moulded spheroid of non-absorbent insulating compound, which also diminishes the tendency to surface leakage between the exposed metal parts on the two sides. These insulators are made in two sizes of 2 in. and 2½ in. diameter respectively, the smaller size being tested by a pull of 2,500 lb. and the larger by one of 4,000 lb.; for each the electrical testing pressure is 5,000 volts.

[illegible]

Fig. [illegible] "Giant" Strain Insulator with Metal [illegible]

An entirely different type of strain insulator is shown in Fig. 1,404, which depicts two such insulators supporting and insulating a trolley wire hanger. The particular pattern shown is made by the Westinghouse Company. The body of these insulators is made of hickory or some other durable hard wood which has been well impregnated with a suitable insulating varnish. Each cap and eye in this pattern is of malleable steel forged in one piece and then pressed cold on to the wood which it grips effectively. The wooden insulating material is always in tension when in use, and can stand a fairly large pull, but mechanically the type is not as good as that previously described.

Fig. [illegible] Strain Insulator [illegible]

Still another type of strain insulator, made entirely of porcelain for high-voltage service, is shown in Fig. 1,405, which depicts a pattern of this type made by the Anderson Manufacturing Company, of Boston. The form is a fluted cylinder pierced transversely by a hole near each end, the two holes being at right angles and having their ends chamfered off. The stranded cables which are to be insulated from one another are threaded through these holes and finished off as shown in Fig. 1,406, in which a Westinghouse porcelain strain insulator is depicted. The chief object of passing the cable through holes in the porcelain instead of round grooves in its ends, is to increase the surface-leakage distance between the cables, though it obviously increases the difficulty of manufacture. The tensile strength of the two sizes of strain insulators of this type as made by the Westinghouse Company is over 16,000 lb. and 23,000 lb. respectively. They will stand a dry test of 20,000 volts, but flash over at [illegible] to 20,000 volts in the rain.

Fig. [illegible]

Uses of Strain Insulators. The chief use for which the strain insulators described above are designed is to provide insulation, or additional insulation, for the ear from which the trolley wire is suspended through the medium of the different types of hangers and suspensions which have also been described.

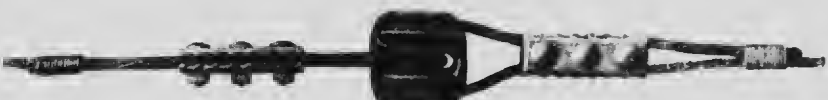


Fig. [illegible] Porcelain Strain Insulator.

An examination of the frontispiece to this volume and Fig. [illegible] will reveal some of these strain insulators in position, but they can [illegible]

Fig. 1,407. Strain Insulators and other Overhead Fittings in Position.

clearly seen in Fig. 1,407, which is reproduced from a photograph of a car storage yard in America, taken by the Standard Underground Cable Company, of Pittsburg. As the effects of perspective, owing to the position of the camera when taking the photograph, are somewhat misleading, it will be interesting to the reader to disentangle the trolley and stay wires and to trace out the trolley wires for the different tracks. He should also endeavour to identify the different overhead fittings.

Fig. 1,408.—Double-suspension Fitting with Strain Insulators.

The actual attachment of strain insulators to a double-suspension fitting is further illustrated in Fig. 1,408, which shows two such insulators, but of a different pattern from those described above, attached to a fitting for suspending two trolley wires which may be used for an up and a down line respectively. Such a fitting is useful in guiding the trolley wires round a curve, the outer rings of the insulators being attached to stay wires fastened to supports at the side of the roadway, in some cases at some distance away.

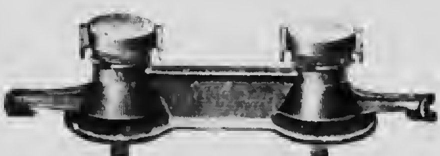


Fig. 1,409. D[illegible] Bolts.

It is interesting to compare Fig. 1,408 with Fig. 1,400 which also shows a "double suspension, but which may be used with an uninsulated suspending cable, since the bolts carrying the trolley wires are separately insulated. It is possible, however, in addition, to place, as can be seen in Fig. 1,407, strain insulators at more distant parts of the supporting cable, and this is frequently done.

These insulators are also used on the "side brackets" and central poles, etc., shown in Figs. 1,442 and 1,443. A couple of insulators with the fitting carrying the suspending bolts between them would be inserted between

Fig. [illegible].—Petrol Motor-driven Tower-wagon for Repairing Trolley Wires.

the points a_1 a_2 in these figures, the whole being strained up fairly tight. The insulators can be seen *in situ* on the cross arms of the centre poles in Fig. 1,441.

Erection and Maintenance of Trolley Wire.—Space does not permit us to describe in detail the process of erection of the trolley wire and the many interesting devices invented to overcome difficulties in connection therewith.

As regards maintenance it is obvious that the trolley wire under the severe conditions of actual service will not last for ever, and that constant watchfulness and rapid repair of faults is necessary if its life is to be prolonged. The wire, however, is suspended at a variable height of 14 ft. or more above the roadway, and there is no support except at poles, etc., for ordinary ladders, whilst efficient inspection from the ground level is impossible. The requirements are admirably met by specially designed motor-driven maintenance lorries, of which a standard American type, made by the White Company, of Cleveland, is shown in Fig. 1,500. These lorries are large enough to carry a good supply of materials for a fairly serious breakdown, but their chief feature is a working platform whose height can be adjusted to the level required for the work in hand, the principle of the telescopic ladder being applied in the supporting lattice work. These lorries are also used in the initial erection of the line and for other purposes, such as hauling obstructions off the track. They are independently driven by petrol or other motors, as it is clear that electric power cannot be drawn from the trolley wire under the conditions depicted in Fig. 1,500, for which the wire must be "dead" to allow it to be safely handled.

The Trolley Wheel and its Supports.—When the picking up of electric energy from an overhead wire by a moving tramcar was introduced in or about 1882, a small roller or wheel, running on the *top* of the wire and pulled along by a trailing flexible attached to the car, was sometimes used, probably because of its simplicity. Such a device was, in view of current engineering nomenclature, appropriately called a *trolley*. It was, however, quickly found to be too crude for the requirements of engineering work, one difficulty being to design supports for the overhead wire which could be readily passed by the over-running trolley wheel and the trailing flexible. The change to an under-running wheel was not long in coming; it quickly supplanted the trolley proper, but retained the name. This change profoundly modified the whole design of the connecting links, including the wheel itself, between the wire and the car, and we have now to describe modern types of these links.

As already explained, the current can be picked up from the overhead wire by either a rolling or a sliding metallic contact. The main advantage of the former is that, if real rolling contact can be attained, it reduces the friction and the wear of the expensively erected overhead wire to a minimum; whilst the latter, as will appear in the sequel, is simpler to arrange from a mechanical point of view. In modern practice the rolling contact or trolley wheel is more frequently used for tramcar and road work, whilst the latter or sliding metallic bow is widely used for railway work. In the present section it is proposed, therefore, to deal with the trolley wheel, and some of the various methods adopted to fulfil the conditions and solve the problems presented, whilst later, in the railway section some account will be given of bow collectors. The use of a sliding shoe instead of a wheel is, however, now being advocated for tramway work, and some particulars are given later.

The trolley wheel itself is a grooved wheel 4 to 6 inches in diameter over all, made of phosphor bronze or some other hard alloy not corrodable under ordinary conditions of exposed outdoor work. Almost innumerable patterns have been devised which may be roughly classified as disc wheels and wheels with spokes. These two general types are illustrated in Figs. 1,501 and 1,502, which represent wheels made by the Anderson Company. In both cases the metal is cast in the form shown; a section of a wheel similar to Fig. 1,502 is given later (see Fig. 1,506). The first problem is presented in the shape of the groove, and the provision of material suitably placed to lengthen the life of the wheel in consequence of the inevitable attrition due to the rubbing of the wheel on the wire, since the contact in practice is seldom a pure rolling contact.

Fig. 1,501.—Disc-pattern Trolley Wheel.

Wheels have been devised in which the flanges are of stamped sheet metal, the bottom of the groove being filled in with cast metal which may be renewed without scrapping the whole wheel. One of these is shown in section in Fig. 1,503. It is a wheel made by the Universal Trolley Wheel Company, of Northampton, Massachusetts, and the details of construction can be readily made out in the figure. The central filling of the groove can be renewed at 70 per cent. of the cost of a new wheel.

Fig. 1,502.—Spoke-pattern Trolley Wheel.

Another difficulty is to provide efficient and suitable lubrication. The wheel either runs with a bushing on a fixed axle, or the axle may not be rigidly fixed, but be capable of turning in the supporting bearings; the wheel, however, as a rule runs freely on the axle. The practical solution of the problem is not easy, for the wheel runs at a fairly high angular speed; for instance, if no allowance be made for slip or the varying level of the trolley wire a wheel making a 5-inch diameter contact when the car is running at 10 miles an hour must make 672 revolutions per minute. For electrical reasons there must, of course, be no lubrication at the interface of the wheel groove and the wire.

The provision of a grease pocket for solidified oil in the hub is illustrated in Fig. 1,503, the bushing being slotted with holes leading to grease pockets in the fixed axle for feeding the lubricant. Graphite bushing and many other devices, some of them very ingenious, have been used to diminish the friction between the wheel and its axle. A graphite bushing made by the Graphite Lubricating Company, of New Jersey, is shown in Fig. 1,504, whilst a wheel with a large oil well in the hub in addition to a graphite bushing, is shown in Figs. 1,505 and 1,506, the latter giving a longitudinal section through the axle. We return to this question in describing the mounting of the wheels.

Fig. 1,503. Trolley Wheel with Renewable Contact Surface.

The next point is to mount the wheel in a suitable trolley "head" designed for attachment to a trolley pole of the necessary length. Two widely used methods, as well as others, are employed, known respectively as the "swivel head" and the "harp." A pattern of swivel head as manufactured by the British Thomson-Houston Company, Limited, is shown in Fig. 1,507. The swivelling arrangement, which at first sight looks complicated, is designed to meet the conditions of service in which the moving vehicle may not always be centrally underneath the trolley wire, notwithstanding which it is essential that the axle of the trolley wheel shall always be at right angles to the plane of the wire. The mounting secures that the wheel and its fittings shall be free to turn round a vertical axis, thus, so far as the above condition is concerned, rendering the position of the wheel relative to the wire independent of the slope of the pole in a transverse direction.

Fig. 1,504.—Graphite Bushing.

Fig. 1,505.

Fig. 1,506.

Trolley Wheel with Oil Well and Graphite Bushing.

The swivelling globe G revolves in hard gun-metal renewable bushes *b*, and carries the wheel and its bearings.

Another method of mounting used widely, especially where the conditions are simpler is the "harp" mounting, a simple form of which is shown in Fig. 1,508; the axle is shown in position, and the general design is obvious. The axle is prevented from turning freely by split-pins driven through diametral holes in its ends, and one of the criticisms of this simple device, which, it will be observed, is used in the next illustration, is that the pins may shake loose and drop out, which will cause trouble. A method of safeguarding this point is illustrated later (Fig. 1,513).

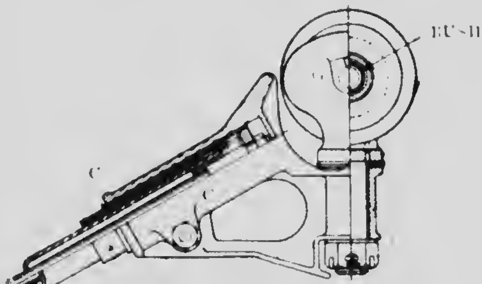


Fig. 1,507.—B.T.H. Swivel Trolley Head.

The next problem which calls for solution is to transfer the current from the rolling wheel to some fixed point or points in the supporting head.

Fig. 1,508.—Trolley Harp.

Now it is obvious that this current, which is often a very large one, cannot readily pass through a oil-lubricated bush to the axle. The necessity for short-circuiting such an electrically bad joint has been pointed out already in several parts of this book. A very usual method of providing this short-circuit can be seen in Fig. 1,508, and better still in Fig. 1,509, which shows the trolley head manufactured by the Universal Trolley Wheel Company, with, in this case, a detachable contact spring, which is also shown separately in Fig. 1,510. The method consists in attaching to the "harp" a flat flexible contact spring expanded at the end into an annular disc which encircles the axle and presses against the flat machined face of the hub of the wheel. Special precautions should be taken in the design to prevent any oily lubricant getting between these two rubbing surfaces. In Fig. 1,508 these springs appear to be simply brazed or soldered to the inner surface of the "harp," but in Fig. 1,509, in which the right-hand fork is represented as semi-transparent, the inner surface of the harp and the bend at the bottom of the springs are so formed and faced that the latter fits into the former, and by the pressure of the compressed spiral spring at the bottom the rubbing surfaces are pressed firmly against the hub. The seatings are kept clean and in good metallic contact by the continual vibration. In this way the current is transferred from the moving trolley wheel to the metal of the fixed trolley head.

The above salient points are further illustrated in Figs. 1,511 to 1,513, which depict the V-K trolley wheel and harp of the More-Jones Brass and Metal Company, of St. Louis. Fig. 1,511 is a side view and Fig. 1,512 a section of the wheel. The hub is made with a bushing of bronze gauze and graphite, which provides a graphitic lubricant free from oil or grease, which should require no further attention when once properly installed. Moreover, as graphite is a conductor (see Table IV., Vol. I., page 752), the current can pass direct to the stationary axle of the harp as well as through the usual contact springs (Fig. 1,513), which in this case press against the annular ends of the graphitic bushing. In this way it is claimed that the conductivity from wheel to fixed harp is much improved, especially as there is no grease anywhere to get under the contact springs. Another modern method of dispensing with oil lubrication is in the use of roller bearings, and trolley wheels to which this device has been applied have been obtainable for some time. Lack of space, however, prevents us from pursuing this interesting subject further.


Fig. 1. Fig. 1,510.
Trolley Harp showing Details of Rubbing Contact.

Another point is the firm fixing, as shown in Fig. 1,513, of the cotters C C, which hold the axle and which are held firmly locked by passing through lock-nuts A, after passing through the axle B. These lock nuts have right and left adjusting screws at their ends, by which the nuts D fixed in the sheet metal of the side flange can be drawn together or slacked

Fig. 1,511. Fig. 1,512.
The V-K Oilless Trolley Wheel.

oft. When drawn together they tend to close the slot K, and thus B is gripped more and more tightly and held locked against vibration. This, it is claimed, greatly diminishes arcing, which is often caused by loose or badly fitting axles. Notwithstanding this rigidity, the axle can be quickly removed and a new wheel mounted when necessary.

The trolley head, of whatever pattern, is attached to the end of a flexible pole, which in modern work is a steel tube from 12 to 17 feet long, and tapering from 2 inches in diameter at the lower end to 1 inch in diameter at the upper end. The pole is protected from the weather, and from accidental electrical contact, should it become "alive," by having its external surface carefully insulated. The British Thomson-Houston Company serve their poles with a double layer of insulating tape, and then with a good coat of black varnish, as well as with an insulating sleeve at the butt end.

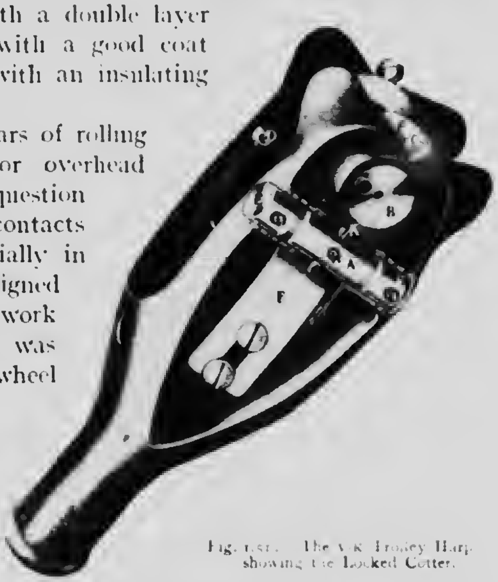


Fig. 151. The V-K Trolley Harp showing the Locked Cotter.

After the use for many years of rolling wheels as contact makers for overhead wires in tramway work, the question of their superiority to sliding contacts began to be discussed, especially in view of the success of well-designed sliding contacts in railway work in Europe and elsewhere. It was pointed out that the trolley wheel does not give a true rolling contact, but that, depending chiefly on the pressure between the wheel and the wire, the contact is a mixture of slipping and rolling, and that the wear during the slipping stages is heavy, because of the small contact surface. Measurements have shown that, at moderate speeds, the slip may be as much as 4 per cent. If it be sought to reduce this wear by lighter pressures destructive arcing occurs, leading to the rapid deterioration of wheel and wire. It was contended that, with the use of a simple sliding contact only, the pressure on the wire, and consequently the wear, could be reduced.

In 1916 these arguments were brought to a practical issue by The Miller Trolley Shoe Company, of South Boston, placing on the market a "trolley shoe" as distinct from a "trolley wheel," which could be used on existing trolley poles by changing the trolley head only. It was recognised that, with the hundreds of thousands of trolley poles with rolling wheels in use, it would be impracticable to propose entirely new gear from the car upwards, and that the line of least resistance was to modify existing gear as little as possible.

Two of the actual trolley heads placed on the market are shown in Figs. 1,514 and 1,515. In Fig. 1,514, which shows one of the earlier types, the familiar appearance of the trolley head is little changed, but the "harp" has disappeared, the "shoe" being supported internally by an extension from the pole socket. There is still a semblance of a wheel, but it is so mounted that it cannot rotate but only oscillate through a moderate angle on each side of a central position. The circular side plates are bolted together, and grip between them a hard steel contact piece C, which gives a bearing surface of about 6 inches in length on the wire, and which can be easily renewed when worn out. There is a graphite bushing which ensures fairly good electrical contact between wheel and axle, but this contact is shunted by a flexible copper shunt S, firmly attached to the fixed and movable parts. The angular "give" of the wheel ensures that the contact piece shall make good and extended contact with the suspended wire at all the varying angles of the span.

Fig. 1,514.—The Miller Trolley "Shoe.

The other figure (Fig. 1,515) illustrates a modification brought out in 1917. The parts have been simplified, and as a sector of a wheel is actually all that is necessary, such a sector only is mounted with the required arc of possible contact. The flanges of the working groove which take up the contact on sharp curves have been made easily renewable, as well as the steel contact piece at the bottom of the groove. A good sliding metal spring at S appears to replace the flexible copper band.

At the time of writing (1917) the new device must still be regarded as on its trial, but it has been given extensive practical tests on many important lines in the United States, and has come out well. With a working pressure of the order of 25 per cent. less than that used with trolley wheels, the life of a trolley shoe with its cheaply renewable contacts is said to be considerably longer. One test shoe ran 18,000 miles on a certain line, and was still good, against an average of 5,000 miles per trolley wheel on the same line. What the effect is on the wear of the wire can only be ascertained by much longer experience.

Ice Cutters.—A condition which may easily cause interruption of traffic and to which all exposed contact conductors are liable, is the formation of a coating of ice on the wire during wintry weather, and especially during sleet storms. Unless the ice be removed it forms a practically insulating covering and stops the service. The action of the passing trolley wheel or shoe tends to keep the wire clear, but particularly when the service is infrequent the mischief may be done at any point between the passing of one car and the arrival of the next, the ice coating formed being too thick or tenacious for the trolley wheel to remove it. The heating effect of the current passing along the wire to other cars helps, but in view of the high latent heat of water it may, and does in practice, often fail to melt the ice.

Fig. 1,515.—More recent Miller Trolley "Shoe"

Before this stage is reached one solution is to replace the trolley wheel by an ice cutter such as is shown at c in Fig. 1,516, which also shows a rapid method of making the interchange devised by the Bayonet Trolley Harp Company, of Springfield, Ohio. In the right-hand side of the figure the trolley wheel and harp w are shown being detached from the pole P, to which they are fixed by a bayonet joint, which is duplicated in the harp C of the ice cutter, which is shown with the end of the trolley pole inserted. No tools are necessary for the transfer, and the change can be made in twenty seconds. In actual working the decreased weight of the head allows the springs of the base to exert a greater pressure on the wire, thus increasing the efficiency of the ice cutter.

Pole Conductors.—The next problem is to transfer the current from the trolley head to the lower end of the pole under safe electrical conditions. Where the pole is mounted on a single-deck car and out of reach of the public the substance of the pole itself can be used as a conductor, the lower end being properly insulated from the car roof. Where, however, the pole is mounted on a car with an upper passenger deck greater precautions must be taken. A reference to Fig. 1,507 will show that the trolley head there is carefully insulated from the metal of the pole. Thus, next to the pole, there is an insulating sleeve, s s, over which slips the contact sleeve c of the trolley head; an insulating bush is placed at i to insulate also a contact terminal and nut, to which a flexible insulated cable passing up through the hollow pole is made fast. What becomes of the insulated cable at the lower end of the pole will appear presently.

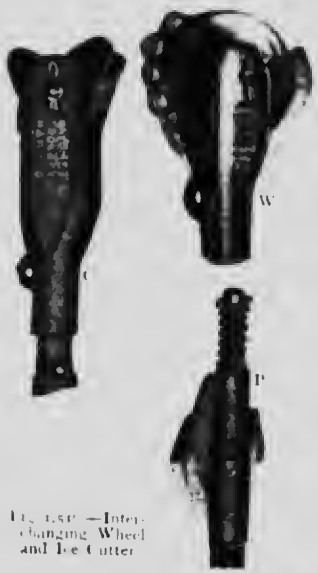


Fig. 1,510.—Interchanging Wheel and Ice Cutter.

Bases for Trolley Poles.—The pole supporting the trolley wheel has itself to be supported so as to comply with certain mechanical and electrical conditions. Of these the principal are governed by the need for following up readily the varying relative distances between the overhead conductor and the car, whilst maintaining a firm contact between the conductor and the trolley wheel. The pole must therefore be so mounted as to have freedom of motion (i.) in a vertical direction, because of the varying vertical distances between the top of the car and the trolley line, and (ii.) in a direction transverse to the track, since, on account of the displacements due to the varying local conditions, the position of the trolley line is frequently far removed from being vertically over the centre line of the track of the tramway. There must, in addition, as we have pointed out above, be arrangements for conducting the current from the trolley head to the fixed circuits inside the car.

Two chief cases have to be considered, their differences being due to the different types of car in ordinary use. In closed single-deck cars or in double-deck cars in which the upper deck is roofed over, the top of the car offers a clear space inaccessible to the public, upon which the necessary fittings can be mounted. In the case, however, of cars which have an open upper deck carrying passengers, or in single-deck cars which are not

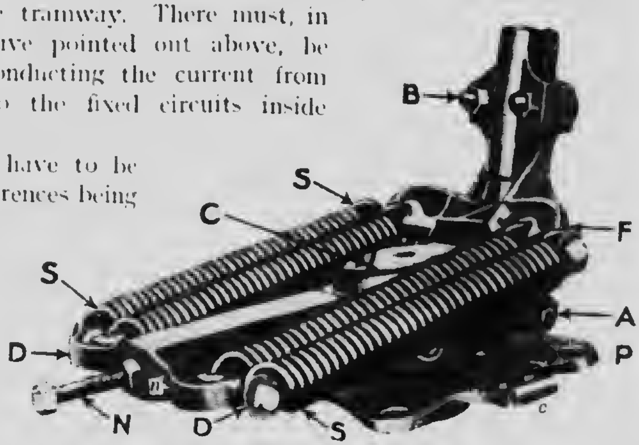


Fig. 1,512.—Schenectady Trolley Base (Form D).

roofed over the base carrying the pole is accessible to passengers, and must be so designed as, on the one hand, to be ensured against injury by the practical inquisitiveness of ordinary or even malicious passengers, and, on the other hand, to make it impossible for the passenger to come into contact with any conductors alive with the fairly high-voltage pressure of the trolley wire.

The case of roofed-over cars being somewhat the simpler, will be taken first, and in Fig. 1,517 there is shown a trolley base for such a car, as designed by the General Electric Company, of Schenectady. A plan and a side elevation of the base on which the principal dimensions are marked are given in Figs. 1,518 and 1,519. The base is supported by a ½-inch plate P bolted to the roof of the car, and provided with central bosses (Fig. 1,519) on both sides. The upper boss forms a bearing cup with the race for the steel rollers, which are inserted between the inner surface of the hollow boss and the outer surface of the inner projection of the upper central stud C, upon which the whole of the movable parts of the base are mounted. The central stud is a kind of inverted cup which, with the bearing cup in the base plate, forms a water- and dust-proof chamber for the steel rollers, which can be well lubricated; and the central stud, running on these rollers and turning round a vertical axis, gives the necessary horizontal or transverse motion to the pole. The details of this central stud, which are important, are shown more clearly on a larger scale in Fig. 1,520.

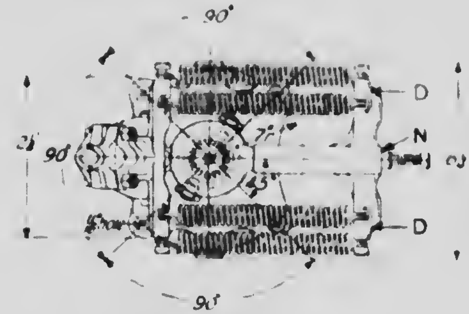


Fig. 1,518.—Plan

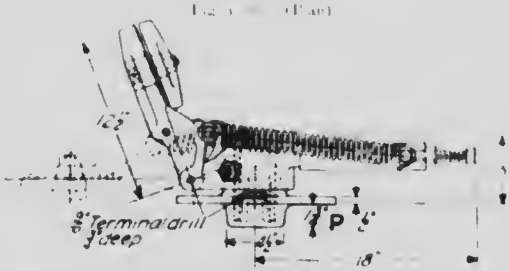


Fig. 1,519.—Side Elevation
Dimensions of Schenectady Trolley Base

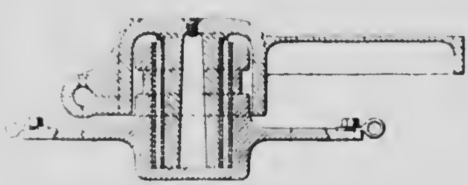


Fig. 1,520.—Detail of Central Stud and Cap with Roller Bearings.

The trolley pole is clamped in position by two ⅝-inch bolts at B (Fig. 1,517); this part, broadened out and ribbed as shown, passes downwards and can swivel in the vertical plane about the axle A mounted on the arm of the central stud, thus securing the necessary vertical adjustment for the position of the trolley head.

The necessary upward flexible pressure of the trolley wheel against the under surface of the overhead conductor is obtained by the action of the four heavy cylindric springs S S, the near ends of which are carried by a heavily-ribbed cross-arm and slide D D, which can be set up and adjusted at N, so as to vary the tension of the springs to any desired extent. The ends of the springs are attached at F to the broadened part of the plate carrying the trolley pole, and when the top end of the latter is depressed the springs are extended, holding the wheel firmly against the wire with a force varying from 20 lb. to 45 lb. The whole base is so designed that the pole can be depressed, as shown by the dotted lines in Fig. 1,519, to the horizontal position, as may be required in going under low bridges or when used on high cars. When in this horizontal position the total height above the top of the roof of the car is only 5 inches. The base which weighs 120 lb. without a pole, is 16¼ inches wide, and has an over-all radius of 18 inches from the central axis to the end of the screw N; it can therefore be turned completely round within the limits of a circle 3 feet in diameter. It is designed to carry a pole 1½ inches in diameter and not exceeding 14 feet in length.

Fig. 1,521.—The Anderson Trolley Base.

Another example of a trolley base which can be placed on the roof of a single-decked car is shown in Fig. 1,521, which depicts a base produced by the A. and J. M. Anderson Manufacturing Company, of Boston. In this case, as in the preceding, the whole of the base is supported by a fixed pin, which rises from a base-plate bolted to the roof of the car. The chief difference in general design, as compared with the preceding example, is that the movable part of the base lies entirely on one side of this pin instead of surrounding it. The fixed pin carries, by means of a suitable cap bearing, a substantial rectangular webbed frame, at one end of which is mounted the transverse axle which carries the trolley-pole clip. The pole is pressed upwards and held in position against the trolley wire by four strong spiral springs mounted as shown; but further detailed description is unnecessary in view of what has already been said with reference to the foregoing example.

Numerous other patterns of trolley bases are in use, but it will be sufficient for our purpose to illustrate two others only as embodying features not yet alluded to. In Fig. 1,522, which shows a "Nuttall" trolley base manufactured in the United States, the spiral spring which presses the wheel against the wire is in compression instead of in tension. The bottom end of the base-pole fitting is attached mechanically to a sleeve, against which the far end of the spring presses and which is drawn nearer to the base when the pole is depressed.

Fig. 1,522.—The "Nuttall" Trolley Base.

In Fig. 1,523, which shows the standard trolley base of the Bayonet Trolley Harp Company, whilst other details are interesting and should be examined, attention is directed to the method at P of inserting the end of the pole in the base fitting. It will be noticed that the pole end works against a spiral spring, and has a certain amount of play. No tools are required to change poles, and it is claimed that sixty seconds is sufficient to make the change.

Current Conduction.—In all the bases shown, the pole, which is of metal, conducts the current to the base, and it is assumed that, notwithstanding the loose contacts necessary to give freedom of motion to the pole, the bearing surfaces are sufficiently large and the metallic contacts sufficient for electrical conductivity to be maintained. Consequently, the end of the flexible from the car circuit is simply inserted into a suitable socket or binding post which is shown at *c* in Figs. 1,517 and 1,523.

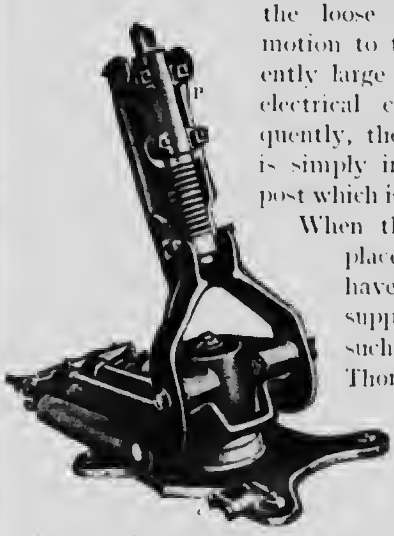


Fig. 1,523.—The "Bayonet" Trolley Base.

When the base supporting the pole has to be placed on an open deck to which passengers have access an entirely different type of support has to be used. An outside view of such a support, as made by the British Thomson-Houston Company, Ltd., is given in Fig. 1,524, and a section showing details in Fig. 1,525. The outer view shows little beyond the base B, the outer tube T, and the revolving head H, the latter carrying the socket K for the trolley pole. It shows also the substantial base plate by which the whole is bolted to the deck of the car, and also the hand-hole *h*, providing access to the contacts at the lower end of the column.

Full details can be made out in the sectional drawing, Fig. 1,525, in which also the end of the trolley pole is shown in its place in the inclined socket. This pole is a steel tube tapering from a diameter of 2 inches at the socket to 1 inch at the upper end; the steel is of such a thickness as to give the necessary flexibility without acquiring any permanent set under the usual working conditions. The pole is protected with a double layer of insulating tape well varnished on the outside, and at the socket is slipped into an insulating sleeve. The socket is of the shape shown in Fig. 1,525; it is pivoted on the pin *p*, and makes a watertight joint with the movable head with freedom to move in a vertical plane round *p*. An extension *a* engages with the trunnion at the top of the tension rod *r r*, which, when the trolley pole is depressed, compresses, through the washer *w* and the guide nut *n*, the strong spiral spring seen in section. This spring, when uncompressed, is over 4 feet long and is made of $\frac{5}{8}$-inch steel rod for short poles and $\frac{11}{16}$-inch rod for poles over 16 feet long. The movable head H revolves on ball bearings in hard gunmetal bushes, which can be renewed without renewing the whole head, thus reducing the cost of maintenance. A weather cap C, which can be removed by withdrawing a screw, closes the top of the column, and allows inspection of the interior when desired.

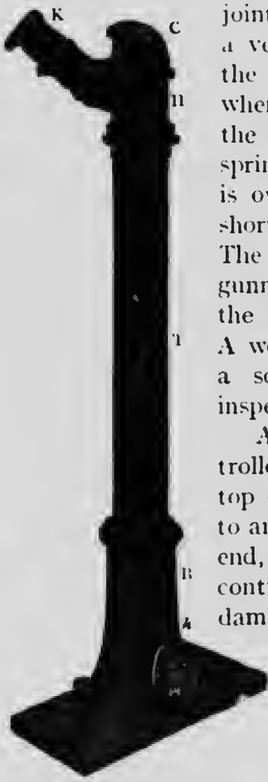


Fig. 1,524.—Column to carry Trolley Pole on Open-deck Car.

An insulated cable conducts the current from the trolley head down the interior of the hollow pole to the top of the column, within which the circuit is continued to an insulated revolving contact *c* (Fig. 1,525) at the lower end, so designed as to allow the head and pole to revolve continuously in either direction without twisting up and damaging the cable.

The over-all height of the standard to the top of the weather cap is 5 feet 6 inches, and it should be noted that the design is such that the trolley pole can be lowered to a horizontal position so that the above gives the minimum clearance required as measured from the deck of the car in passing under low bridges.

Similar standards, to meet the conditions set forth, have been designed by other firms, but the above example is sufficient to show generally the methods of solution adopted.

The Return Circuit.—One of the outstanding features of the overhead trolley system, as used for the transmission of continuous currents to a moving tramcar, is that it only provides a single insulated conductor, and that therefore the circuit back to the generating station or the substation, as the case may be, has to be provided by what is technically known as the "earth." As a matter of fact, the rails on which the cars run are themselves conductors, and are mechanically continuous for the whole distance traversed by the cars. It is not surprising, therefore, that in order to save the cost of erecting and maintaining a second insulated conductor, engineers, from practically the earliest days of tramway electric traction, should have utilised the rails for their return circuit. The general idea is that the current, having passed through the car motors, should then pass to the under frame of the car, whence, finding its way to the running wheels, it passes into the running rails through the metallic contact between the wheel and the rails. At the generating or sub-station, as the case may be, proper arrangements are, of course, made to connect up the rails so as to complete the circuit.

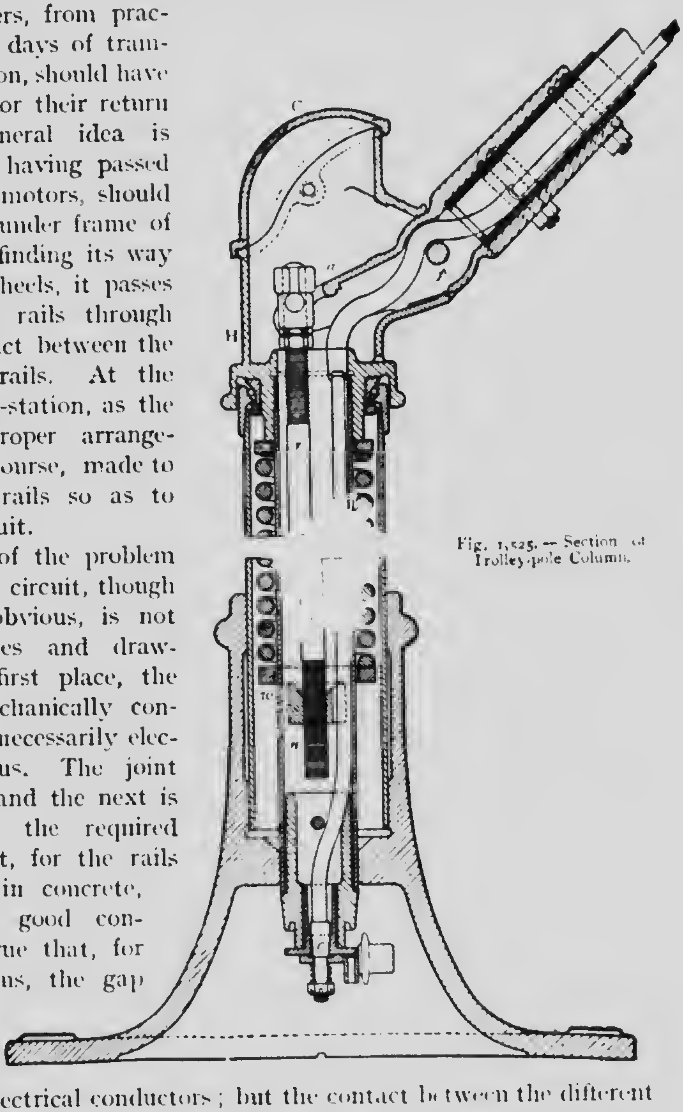


Fig. 1,525.—Section of Trolley-pole Column.

This solution of the problem of completing the circuit, though so simple and obvious, is not without difficulties and drawbacks. In the first place, the rails, though mechanically continuous, are not necessarily electrically continuous. The joint between one rail and the next is a weak spot in the required conducting circuit, for the rails are usually laid in concrete, which is not a good conductor. It is true that, for mechanical reasons, the gap is bridged by fish plates or other mechanical devices which are electrical conductors; but the contact between the different metallic pieces may be, and often is, electrically bad and may offer a considerable resistance to the passage of the current. The difficulty is minimised either (i.) by bonding the rails together with copper bonds, or (ii.) by solidly welding them together *in situ*. It will be convenient, however, to postpone further consideration of the subject until we have described the methods in use for conveying energy to moving railway trains (*see* page 1513).

Another difficulty is caused by the fact that the rails, not being insulated, but in electrical contact at places with the earth, leakage currents flow into the earth, which is made part of the circuit. At first sight this may appear to be an advantage, for the conductivity of the whole circuit is thereby increased, the earth and the rails being electrically in parallel. Because the currents are heavy ones, however, and may pass *en route* into all kinds of conductors buried in the ground, electrolytic corrosion may take place to a serious extent in these other conductors, and this may give rise to serious trouble, to which also we refer later when dealing with rail returns.

Fig. 1,526. Railless Traction at Bradford.

Railless Traction.—It will be convenient to interpolate here a brief description of a method closely associated with the foregoing, of supplying energy electrically to moving vehicles, other than those tramcars, etc., which run on special rails. The rails, it is obvious, though convenient, are not necessarily a part of the overhead trolley system, which, plainly, can be utilised to supply energy to any vehicle within reaching distance of the overhead conductors. The distinctive features of the rails are:—

(i.) That they provide a perfectly definite route for the vehicles;

(ii.) That this route offers much less resistance in the form of friction than the ordinary roadway does to vehicles with ordinary wheels; and

(iii.) That the rails, when bonded, provide a conducting path for the current, and that therefore it is only necessary to insulate one of the conductors conveying the electric energy.

Rails, however, are costly to lay and to maintain, and moreover their use as return conductors for the current is not without its disadvantages, which are pointed out elsewhere (*see* page 1567). As usual, therefore, in most practical engineering problems, the solution now fairly widely adopted is a compromise embracing disadvantages as well as advantages, and it may be that under certain conditions other compromises will prove to be more economical or convenient, or both.

One of the other possible solutions of the general engineering problem under consideration is to be found in the "railless trolley," examples of which were inaugurated as recently as 1911 simultaneously in the neighbouring towns of Leeds and Bradford. A general idea of the method can be obtained from Figs. 1,526 to 1,528, the two first of which are illustrations taken from the Bradford system, and the last from Leeds.

Fig. 1,527. The Railless Vehicle Reversing at a Terminus.

In Fig. 1,526 the railless trolley vehicle, in the shape of a large single-decked omnibus, is shown passing, on the "left" side, other traffic on an ordinary road. Power is obtained by a double under-running trolley from two overhead wires, the trolley and the wires being similar and similarly mounted to those used in the ordinary overhead single trolley system already fully described. Two overhead wires, however, are necessary because the return path by the rails is, of course, not available. This also renders necessary the use of two trolley poles, the heads of which must be insulated from one another and which complicate the details of the trolley base on the roof of the vehicle. The trolley poles are so mounted as to allow the vehicle to run towards either side of the road to the full extent of their length.

The particular vehicle shown not being double-ended like a tramcar must be reversed at the end of its route. This reversal is accomplished by running the overhead conductors round a semicircular arc, as shown in Fig. 1,527, which represents the Dudley Hill terminus of the Bradford system.

Fig. 1,528.—The Railless Vehicle passing under a Bridge.

The adaptability of the system to varied road conditions is shown in Fig. 1,528, in which the vehicle is depicted passing under a somewhat low railway bridge at Leeds.

The vehicle shown was driven through a series-parallel controller (described later) by two 20-H.P. traction motors with shunted fields, the drive being through worm gears and chains to the rear road wheels, which were solid-rubber tyred. The steering gear was on the front wheels, and the vehicle could be turned round in a radius of 12 feet measured on the inner driving wheels. A deviation of 15 feet measured to the centre line of the vehicle was possible on either side of the centre line of the overhead conductors. Seating accommodation was provided for 28 passengers in each vehicle.

Fig. 1,529. Diagram of Insulation Arrangements at a Junction.

There being two insulated conductors and two trolley wheels at different potentials, problems similar to those which occur in the open conduit system occur at crossing points and turn-outs. In the latter system it will be pointed out in due course that to avoid short-circuits the live conductors are completely interrupted at these places, and the car having lost all power has to coast past these "dead" points. This gives rise sometimes to awkward blocks where the traffic is crowded, and the car is compelled to pull up before it has quite covered the required distance. The difficulties would be still more awkward if the railless vehicle became "dead" at a crowded traffic point, and though similar solutions were suggested it was seen that the principle of interrupted conductors for so long a distance was wrong. The solution actually adopted in the end was a simple one. It is shown diagrammatically in Fig. 1,529, and as actually erected in Fig. 1,530. Solid cross-overs and frogs are employed at the crossing points of the conductors, but at the points A (Fig. 1,529) their ends are built up in section-insulator frames (*see* Fig. 1,484, page 1401), so that the trolley wheel only loses live contact whilst running on fibre for a very short length of the conductor route.

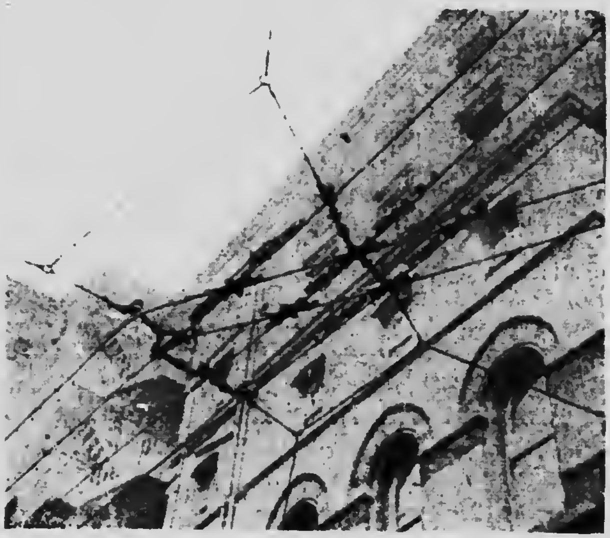


Fig. 1,530.—Crossing of Positive and Negative Overhead Conductors.

Other towns and districts have later adopted railless traction to solve special problems. For instance, at Brighton a route 2,100 feet long was laid out by the Corporation in the centre of the town, and on this route was run a railless trolley double-deck bus, which was the first of its kind. Other developments are in progress.

III.—THE OPEN OR SLOTTED-CONDUIT SYSTEM

We now pass to the second of the general methods scheduled on page 1382 which are in use for supplying electric power from a generating or sub-station to a moving tramcar.

The general idea of the method is to place insulated conductors in an underground conduit running the whole length of the track, and to provide some method by which the current can be conveyed from these conductors to the moving vehicles. For this purpose a "plough" suspended from the vehicle passes through a narrow slot on a level with the general surface of the road, suitable contacts on the plough being arranged to slide on the live conductors in the conduit. The general scheme of the conduit as usually constructed is shown quite diagrammatically in Fig. 1,531, in which the slot S is over the centre line of the conduit, and the conductors C C′ are supported no either side of this vertical centre line.

The diagram shows pretty clearly the conditions which must be fulfilled in the design of the conduit. The most important mechanical condition is that, whilst keeping the centre line, V V, quite clear for the passage of the plough, the conduit must be constructed of such strength as to resist the crushing effect of the heaviest ordinary traffic the roadway may be called upon to bear. It is obvious that if the wheel of a heavily-loaded vehicle should happen to run along the line of the slot, the slot, if the construction be too weak, may be partially closed, and the next plough which comes along may be gripped by the closed-in sides. As no support can be allowed across the centre line, the condition is not an easy one to satisfy mechanically. It goes without saying that, apart from the slot, the conduit itself should not be in danger of being crushed in by the road traffic, but this condition can be readily satisfied.

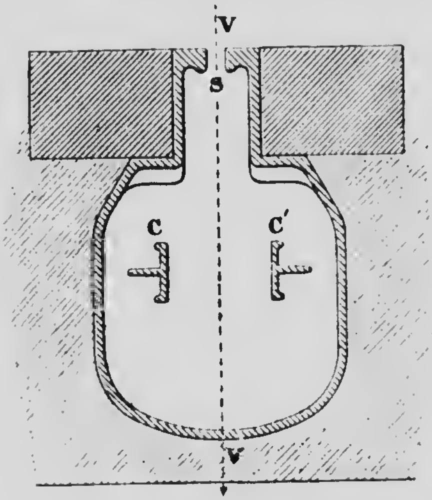


Fig. 1,531.—Diagrammatic Section of a Conduit.

Some other minor conditions are that arrangements must be made for draining and cleansing the conduit, and for access to it for repairs of the insulators and conductors, with special arrangements for the problems which have to be solved at crossings and turnouts.

The first line to be laid down on this system in this country was a short line of about two miles in length, which was constructed at Blackpool as far back as 1885 by Mr. Holroyd Smith. The details of this line are now only of historical interest, and it will suffice if we give in Fig. 1,532 a cross-section of the conduit at one of the positions where the + and − conductors F F are supported by the insulators E E. The details of construction can be sufficiently well made out from the illustration. The conduit A was about 12 inches deep, the slot was ½ inch wide, and a suitable plough, or collector, suspended from the car made the necessary contacts with the conductors F F.

There is a long period in point of time between the above and the next examples, and during this period much experimental and other work was done in various parts of the world.

A notable example of this system is given in the London County Council Tramways, in connection with which over 100 miles of double track have been laid down with slotted conduits. In addition, there was a much shorter length of similar track at Bournemouth. Similar systems have also been installed at Paris, Brussels, Berlin, New York and elsewhere in Europe and America. Not only because of its importance,

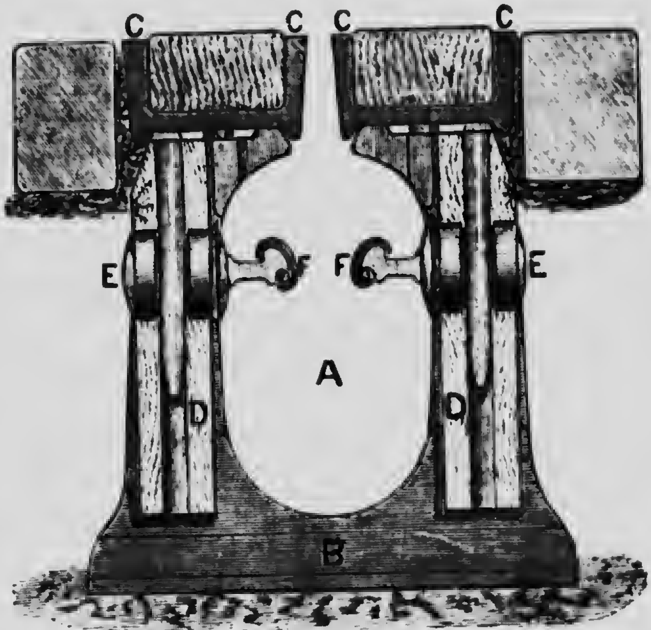


Fig. 1,532.—Some Details of the Blackpool 1885 Conduit.

but also because of its interest to English readers, most of the details to be given below will be drawn from the London system.

In modern methods of construction the slot, upon the accurate laying of which so much depends, is bounded on either side by specially rolled and substantial steel rails. A dimensioned cross-section of one of these rails, designed for the London County Council tramways, is given in Fig. 1,533. The face of the slot is at A, and the section shows two holes, one, H, for bolting to a cast-iron yoke, and the other, H', for a tie-rod, which will be referred to later. These rails are supported by cast-iron yokes placed vertically in a trench, the digging of which forms the first stage of the work, provided no obstructions have to be cleared out of the way. The general method of construc-

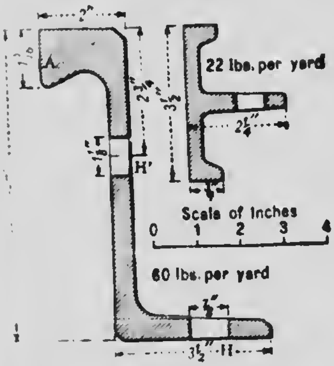


Fig. 1,533.—Slot and Conductor Rails.

tion, as followed in the earlier sections laid down, will be readily gathered from a careful inspection of Figs. 1,534 and 1,535. In the first of these (Fig. 1,534) the slot rails and yokes are shown in position in the trench, being temporarily supported by wooden bearers until the concrete conduit has been built up round them *in situ*. The way in which the rails rest on and are secured to the yokes is shown in Fig. 1,535, which gives full details, with dimensions, of the yokes shown in Fig. 1,534. The pattern is that used in the earlier sections of the work on the south side of the Thames; for much of the later work it was replaced by a more elaborate yoke, which will be referred to subsequently. It will be noticed in Fig. 1,535 that the slot rail rests on, and is bolted with two bolts (*see* Fig. 1,533) to, a seating *a* on the yoke, which overhangs the conduit, and that it is stiffened against closing the slot by an iron tie T, which drops into a special lug *l* on the yoke, and passes through a hole H′ (Fig. 1,533) in the rail; the method of tightening up the tie-rod with nuts can easily be made out. In Fig. 1,534 a few of these tie-rods, but not all, are shown in position. The yokes were heavy, weighing 160 lb. each, and were placed 3 feet 9 inches apart, centre to centre.

Fig. 1,534.—Slot Rails and Yokes in Position.

The width of the slot on these first-laid lines is ¾ inch, which is much more convenient than the ½ inch which was all the road authorities would allow Mr. Holroyd Smith to use at Blackpool. In the lines laid down later on the north of the Thames, the restrictions were still further relaxed, and these more recent slots are laid a full inch wide.

The completed conduit of the earlier type, as shown in Fig. 1,536, is cast in concrete around wooden formers which are fixed between adjacent yokes and withdrawn after the concrete is set. The concrete wall of the conduit so constructed is about 6 inches thick, with an extra 4 inches at the yokes. These formers are shown in place ready for the filling in of the concrete in Fig. 1,537, which represents a stage in the construction of the Bournemouth tramways, which in many respects resembled the London ones, and were constructed about the same date (1902–3). The conduit so formed is 14½ inches wide at its greatest width inside, and its bottom surface is 24 inches below the surface of the road.

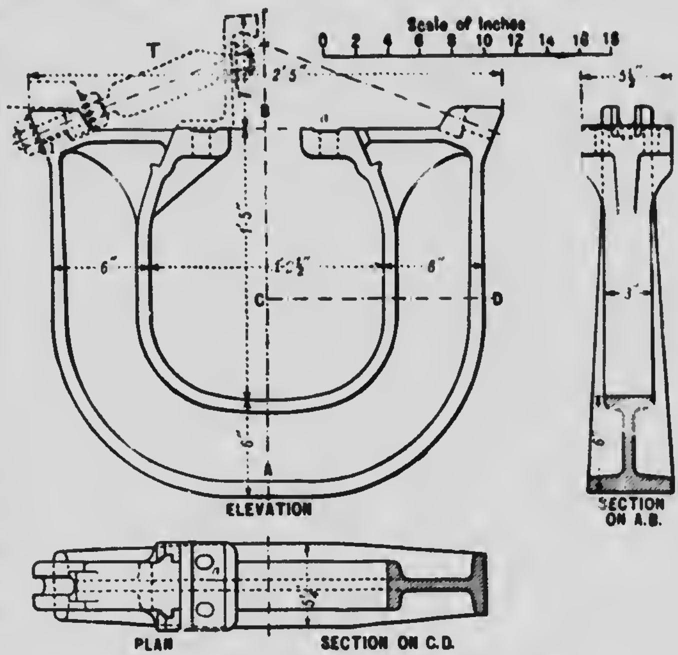


Fig. 1,535. Short Yoke used on the London Tramways

The Conductor Supports. — The methods of supporting and insulating the conductors are important details in the open-conduit system of supplying energy to the moving car, for it is evident that the consequences of any breakdown of insulation or of mechanical rigidity, due either to faulty design or construction, would be serious and repairs difficult, because of the general inaccessibility of these conductors.

The method adopted in the earlier London constructions of supporting the conducting rail and providing access for inspection and repair to the insulators are shown in detail in Fig. 1,538. The holes at the sides of the rails seen in the foreground of Fig. 1,537 are at the positions of the insulators, which are 15 feet apart, and are bolted to the slot rails as shown in Fig. 1,538, which gives a cross-section through the insulator in its tion as followed in the earlier sections laid down, will ... gathered from a careful inspection of Figs. 1,534 and 1,535. In the first of these (Fig. 1,534) the slot rails and yokes are shown in position in the trench, being temporarily supported by wooden bearers until the concrete conduit has been built up round them *in situ*. The way in which the rails rest on and are secured to the yokes is shown in Fig. 1,535, which gives full details, with dimensions, of the yokes shown in Fig. 1,534. The pattern is that used in the earlier sections of the work on the south side of the Thames; for much of the later work it was replaced by a more elaborate yoke, which will be referred to subsequently. It will be noticed in Fig. 1,535 that the slot rail rests on, and is bolted with two bolts ... Fig. 1,535) to a seating *a* on the yoke which overhangs the conduit, and that it is stiffened against closing the slot by an iron tie-rod, which drops into a ... lug *l* on the ..., and passes through a

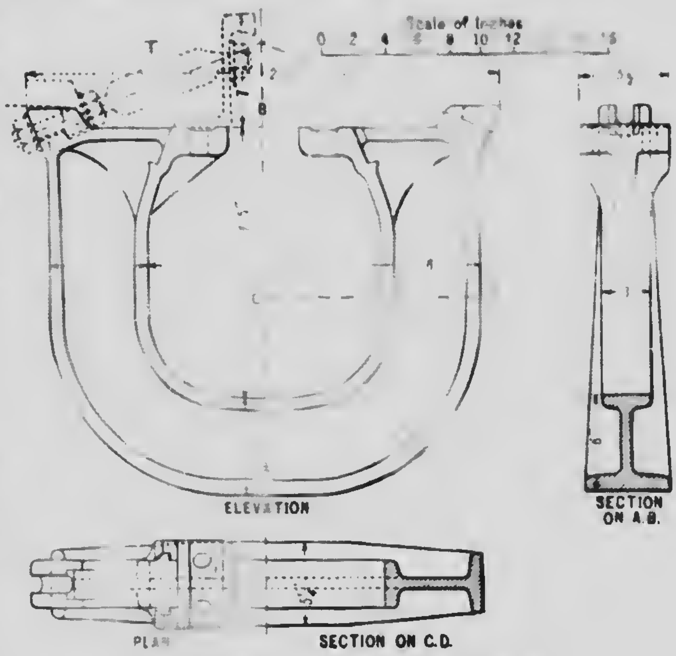
Fig. 1,534.—Slot Rails and Yokes in Position

hole *r'* (Fig. 1,535) in the rail; the method of tightening ... the tie-rod with nuts can easily be made out. In Fig. 1,534 ... of these tie-rods (but not all) are shown in position. The yokes were heavy, weighing 160 lb. each, and were placed ... feet 9 inches apart centre to centre.

The width of the slot on these first-laid lines is $\frac{3}{4}$ inch, which is much more convenient than the $\frac{1}{2}$ inch which was all the road authorities would allow Mr. Holroyd Smith to use at Blackpool. In the lines laid down

...ter on the north of the Thames the ...striction w... still ... laxed, and these more ... ent slots are la... full ... h w... e.

The completed conduit of the earlier type, ... shown ... in Fig. ... cast in concrete around wooden formers wh... h a... ... yokes and withdrawn after the concrete is ... the conduit so constructed is about 6 inches th... w... the ... kes. These formers are show... in pl... ... ady ... the concrete in Fig. 1,537, which rep... sent ... tag... ... of the Bournemouth tr... ways, ... h... in ... d the London ... ones, and ... con structed about the same date (190...). The co... it so formed ... 14½ inches wide at it greatest width inside, and its bottom surface is 24 inches below the surface of the road.



... Yoke used on the L... ...

The Conductor Supports. – The ...thods of sup... ting and in... ating the ...ducters are ...tant de... ... open ... of supplying energy to the moving car, ... is ... t th... ...nces of any breakdown of insulation or ... to faulty design or construction, would ... serio... ... rep... because of the general inaccessibility of ...se ...

Th... ... earlier London constructions of support... ... ...ding access for inspection and repair ... shown ... detail in Fig. 1,538. The holes at the sides ... foreground of Fig. 1,537 are at the positions of the ... 15 feet apart, and are bolted to the slot tails as shown F... ... gives a cross-section through the insulator in its position on the rail to which it is bolted by two bolts B. The insulator itself consists of a cast-iron cap *c*, with a side flange *f* for attachment to the rail, and a lip *l* to shed water. The insulating material is a cup of porcelain, *p p*, which is cemented into the iron cap, and has, in its turn, cemented into it a wrought-iron bolt *b*. Cap, porcelain, and bolt are all corrugated to enable the cement to get a good grip upon them. A cast-iron clip C projects horizontally from the lower end of the bolt, to which it is securely bolted, eccentric washers being used for the final adjustment. This clip carries the conductor rail, which is of T-section and is securely bolted to it. The cross-sectional dimensions of this conductor rail are given in Fig. 1,533, and each rail is 30 feet long, the weight being 22 lb. per yard. The vertical faces of the conductors are fixed 6 inches apart, each being 3 inches from the vertical plane passing through the centre line of the slot. The method of supporting the conductor and slot rails is shown in perspective in Fig. 1,539, which will help to make the above descriptions clearer.

Fig. 1,536.—Conduit Completed.

The hand-hole and its cover, by removing which access can be obtained to the insulator for inspection and repair, must not be overlooked. As constructed in the earlier sections, a framing is let into the surface of the street, as shown at A, Fig. 1,540, which gives a plan of a short length of single track; whilst a vertical cross-section at the insulating pit is given in Fig. 1,541. These illustrations explain the whole arrangement, and reference can be further made to Figs. 1,536 and 1,537, in which the boxes for these hand-holes can be seen in the unpaved street. The appearance of the paved street at one of the insulating points is shown in Fig. 1,540.

For comparison, some details of the methods adopted in Paris and in

Washington for the same purposes are given, partly in section, in Figs. 1,542 and 1,543. In both the method of insulating and carrying the conductor rail is very similar to the London method, the differences being chiefly in the method of support of the insulator cap which directly supports the porcelain insulator. The Paris method (Fig. 1,542) differs from the London one only in supporting the cap by means of a lug at the level of the top of the cap instead of nearly half way down. In Washington (Fig. 1,543) the cap is made part of a more complicated fitting, and is brought much nearer the surface of the road. It is contained in a box which provides a seat for an extension of the top of the cap. The box is closed by a shallow cover let into the surface of the road and abutting on the slot rail.

Fig. 1,537.—Side-slot Conduit in Course of Construction.

Further Conduit Details. — The slot rails so laid are, on the London tramways, placed in the centre of the track, as shown in Fig. 1,544, which is a view of a portion of the unfinished track at a switching point before the surface pavement of the road is laid down. Cross-sections of the track at a yoke and between the yokes are given in Fig. 1,545, and show to scale the relative positions of conduit, the slot rails and the running rails. The sketch also shows the rods which are fixed at intervals between the slot rails and the running rails for the purpose of keeping the slot from being closed by heavy traffic coming on to its rails. Similar ties were sometimes placed between the lugs on the yokes and the running rails, this extra tie being made fast to the bolt of the slot-rail tie already referred to.

In the Bournemouth tramways, although the general principle of the construction of the conduit was the same, the slot rails were modified in section and used for one of the running rails, except at crossings and switching points, where they were brought to the centre of the track as in London. A cross-section of the Bournemouth track at a yoke is given in Fig. 1,546, and another cross-section between yokes in Fig. 1,547. The difference between the slot rails here shown and those illustrated in Fig. 1,533 can be easily made out; the other details do not call for further notice. It may, however, be pointed out that the gauge is 3 feet 6 inches as against the English standard railway gauge of 4 feet 8½ inches, which is used on the London tramways.

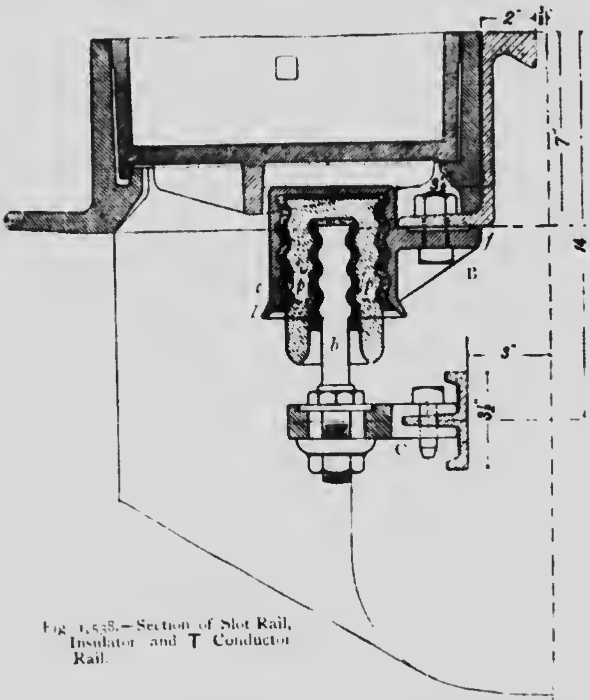


Fig. 1,538.—Section of Slot Rail, Insulator and T Conductor Rail.

The construction of the London County Council Tramways, on account of the magnitude of the undertaking, which up to the beginning of 1915 had cost over eleven millions sterling, was necessarily spread over a long period of years, and, as might be expected, improvements were made in various details of construction as the work progressed. Only one or two of these, however, need be noticed here. One of them is the gradual replacement of the yoke shown in Fig. 1,535 by an extended yoke (Fig. 1,548), designed not only to carry the slot rails, but also the running rails. The side webs of the short yoke have been extended horizontally to beyond the position of the running rails, and terminate in bolting-up faces, on which the running rails rest, and are bolted up with suitable packing pieces inserted. The tie-rods of the slot rails are made fast to the running rails, instead of to lugs in the yokes. On some routes these extended yokes were used in the proportion of one to every two short yokes, on others they are used alternately with the short ones, whilst in some special positions all the yokes are extended yokes. Their use gives greater solidity to the whole structure,

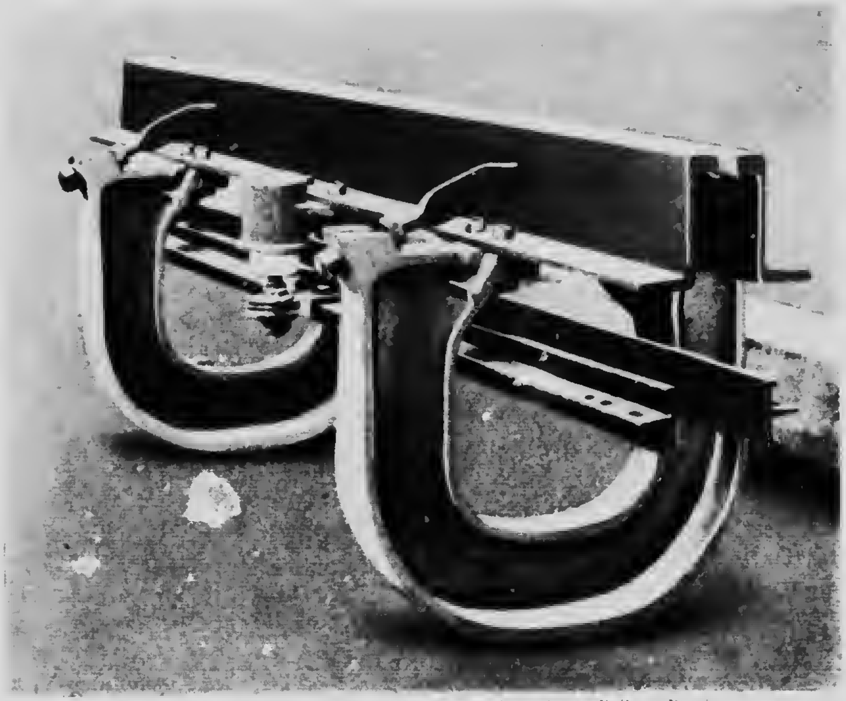


Fig. 1,539.—Yokes with Slot Rails, Insulator, and Conductor Rails in Position.

and diminishes the risk of relative motion between the various parts. The drawing is fully dimensioned.

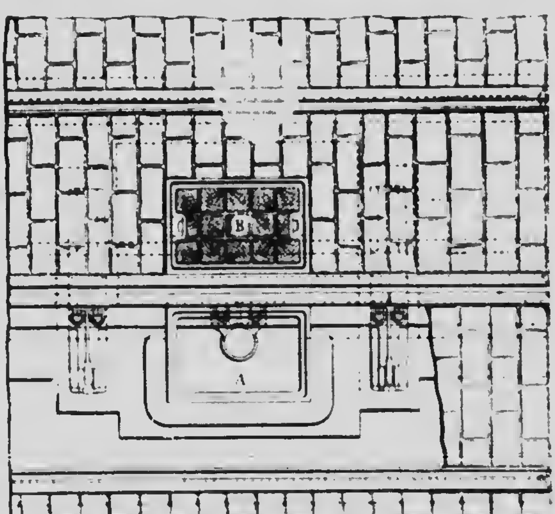


Fig. 1,5[illegible].—Plan of Track showing Insulator Hand Hole.

It is interesting to note the differences between the extended yoke used in London, and the similar yoke used in Washington, which is shown in Figs. 1,549 and 1,550. In the American yoke, it will be noticed that the tie rods from the slot rails, instead of being made fast to the running rails, are attached to special lugs L L on the yoke, well inside

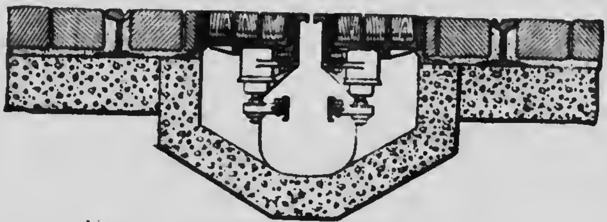


Fig. 1,541.—Insulating Pit, showing Hand-hole Covers

the position of the running rails. Other minor differences will also be observed. Incidentally, the figure gives also in the plan (Fig. 1,550), and partly in section, some further details of a short length of the track, in which attention may be drawn to the different cross-section of the slot rails. The covers of the insulator boxes are shown at A B. These boxes, as in London, are 15 feet apart; some details of them have been already given in Fig. 1,543. The vertical depth from the street level to the bottom of the conduit is 25 inches, as against 24 inches in London.

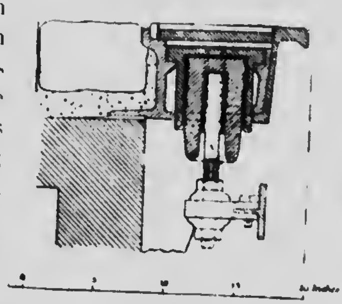


Fig. 1,543.

Fig. 1,54

Other Methods of Supporting Insulators.

Another change in London, and one which has made a marked difference in the appearance of the finished track, is the replacement of the cast-iron box covers of the insulator hand-holes, as shown at B, Fig. 1,540, by shallow cover plates, over which the ordinary paving of the road is laid. Hand-hole covers, at about 15 feet apart, showing on the surface of the road, are objectionable, not

Fig. 1,544.—A Portion of an Unfinished L.C.C. Track before the Paving is Laid.

only because of their unsightliness, but for other reasons. Their chief advantages are that the positions of the insulators are readily indicated, and that when inspection or repairs are necessary the permanent surface of the road need not be interfered with. Balancing advantages and disadvantages in other directions, it was decided to construct many of the London lines on the north side of the Thames with the insulators supported and covered up as shown in Fig. 1,551, which should be compared with Fig. 1,538. The positions of the insulators are now indicated to the initiated by a slight modification in the paving, which does not attract observation. They can also be ascertained by direct observation by lowering down a plane mirror suspended by cords into the conduit; the light coming down through the slot and reflected from the mirror not only enables the observer to see the insulator, but also partially to inspect it and at least to determine whether it is seriously damaged. It will be seen that the method of attaching the insulator cap to the slot rail is practically the same in both cases, but that in the later form (Fig. 1,551) the cap is protected by a simple sheet of iron properly supported, and that directly over this there is placed a paving block somewhat shallower than the other blocks used, so that the block pavement of the road appears to be continuous except, as already explained, to the initiated.

Crossings and Junctions.—One of the serious objections to the open-conduit system as compared with the overhead trolley system is the complication which arises at crossings and junctions. In the first place, for electrical reasons, since both + and — conductors are in the conduit, it is necessary, in the method of construction above described, to interrupt the **T**-rails altogether and to trust to the car being carried on

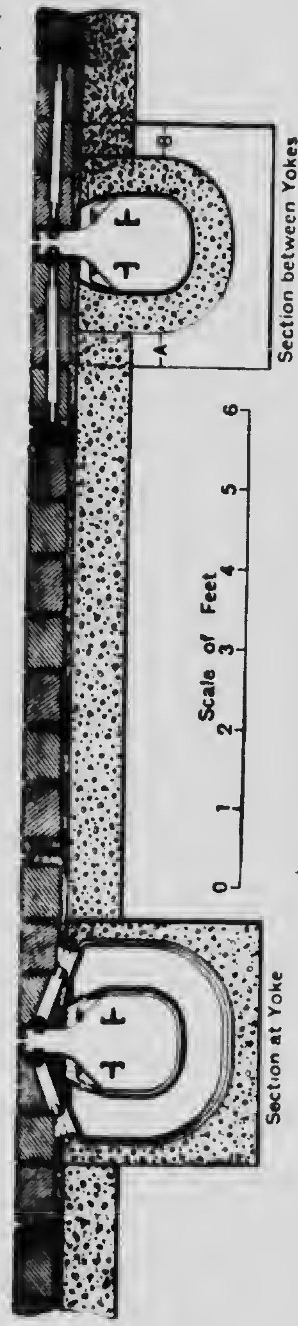


FIG. 1,545. Crosssection of Track in South London past the interruption by its momentum, and without the assistance of the current. At right-angled crossings the break need only be 2 or 3 feet long, and at other places it is not usually longer than 8 feet; at the worst crossings, however, where the angle is very acute, the break may be as much as 12 feet long. Thus at complicated junctions repeated interruptions occur, and at night time the lamps in the car go out at

Fig. 1,546 Fig. 1,547.
Section of Conduit Track at Yoke and between Yokes.

each of these, to the annoyance of some of the passengers. A more serious difficulty is that, owing to some unusual circumstance, it may occasionally happen that the car's momentum is not sufficient to carry it over the interrupted section, or through an emergency application of the brakes the car stops in a position in which it is impossible for it to obtain any electric energy. In such cases there is nothing for it but to

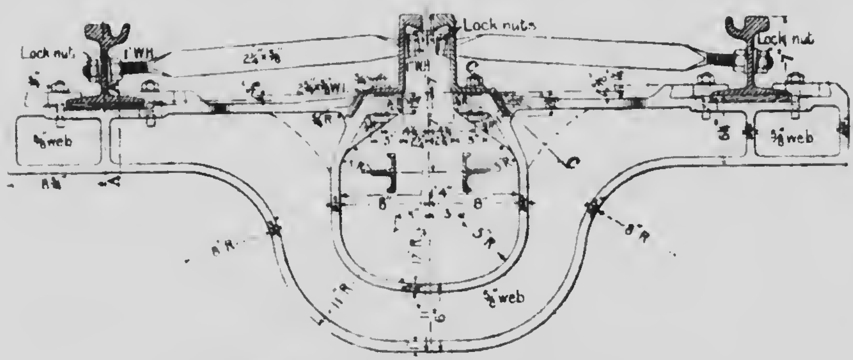


Fig. 1,548. Extended Yoke used on the L.C.C. Tramways.

push the car past the dead point or to wait for another car to come to its assistance.

In the second place, at every switching point very carefully designed mechanism must be constructed, and maintained in a state of efficiency, to ensure that when the wheel switches are thrown over the plough switch also goes over without fail. If by any chance the car wheels were switched on to one track whilst the plough continued its course along the slot of

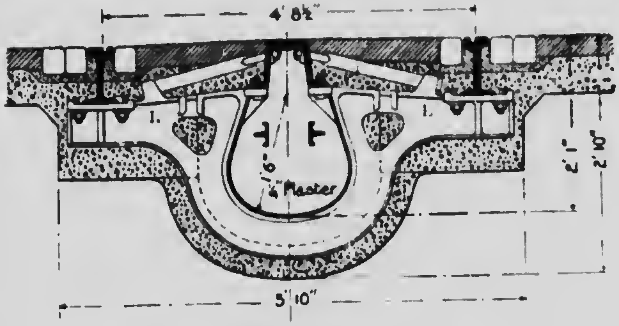


Fig. 1,549.

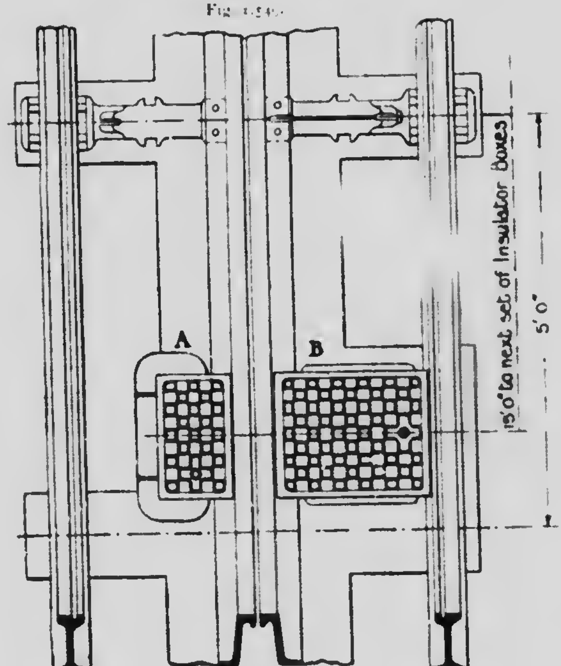


Fig. 1,5[illegible]
Details of Conduit, Rails, Extended Yoke, e[illegible] ed [illegible] Washington

the other track, the plough and the car would have to part company in a way which may be disastrous to both. The switching problem is not, therefore, so easy as with the overhead trolley, where at a pinch the motorman can lean over the front of his car and push a single switch rail over with a hand rod. Some idea of the increased complication will be formed by an inspection of Figs. 1,552 and 1,553, reproduced from *Engineering*, which give details in plan and vertical cross-sections of the switching gear used on the early South London tramways. In the plan (Fig. 1,552) we see that the wheel switches *w*, *w*, which determine the direction of path open for the wheels, must move in the opposite direction to the plough switch *p*, which determines the direction of travel of the plough. That there may be no error, the mechanisms which control these movements must be interlocked so that the switches must all move together and be moved from a single point; moreover, any connecting rods which

Fig. [illegible]51. Paving Block Cover of Insulator.

pass under the slot must pass at a level sufficiently low to clear the plough. The mechanisms are shown in plan in Fig. 1,552, but their mode of action can best be studied in Fig. 1,553, which is a vertical cross-section through A B in Fig. 1,552. The mechanisms are operated by a lever inserted at L (*see* both figures), or by a more distant lever, placed within the kerb of the roadway and operating the horizontal rod *r* (Fig. 1,553). To assist the reader in mastering the details, it has been assumed that the rod *r*, or the connecting link R, are being moved from left to right, the diagram showing them just at the end of this movement. Small arrows, *a a a*,

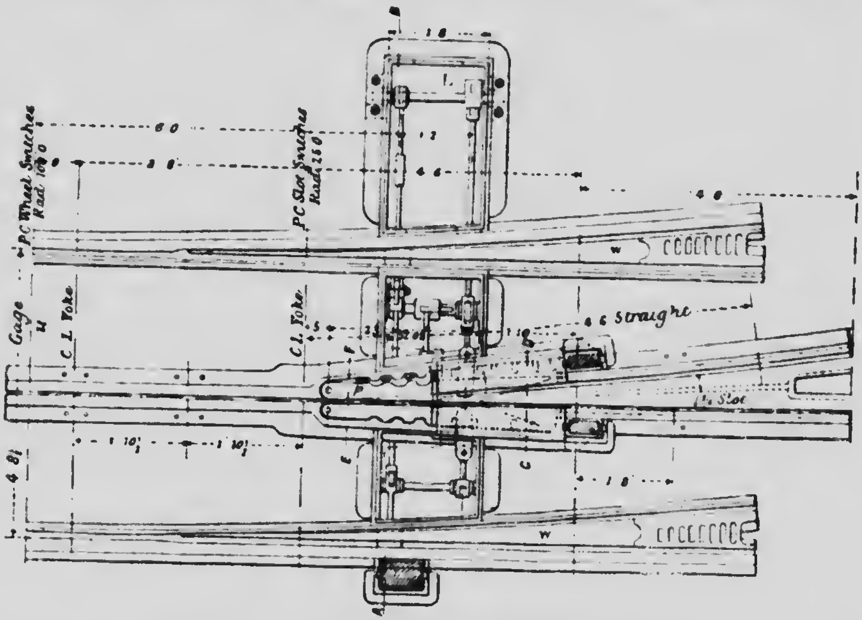


Fig. 1,552.—Plan of Wheel and Plough Switches at a Switching Point

have been placed near the horizontal parts of the mechanism to show the simultaneous direction of motion of these parts. Numerous dimensions are inserted on both figures, and give interesting details of actual sizes.

It has been mentioned above that one of the essential details in the design of the conduit is the provision for draining and cleansing. Sumps or drain pits are constructed for drainage at all special points and in convenient positions along the ordinary track. They are connected to both conduits of the double track, as shown in Fig. 1,554, by a 12-inch pipe and to the sewers by a simple trap. It is possible to cleanse the conduits by careful flushing towards these sumps. It would carry us too far from our main subject to discuss the various methods adopted for the draining and cleansing of the conduits. These details belong rather to the domain of civil engineering, and considerations of space forbid us to enlarge upon them. The necessity for making such provision is what we desire to insist upon here.

The Travelling Plough. — Although the plough which makes connection between the moving car and the conductor rails is a part of the car equipment, it is so essentially a feature of the slotted conduit system, and indeed, because it is one of the weakest links of that system, it will be better to describe it here, rather than in connection with the equipment of the cars. In doing so, we are following the precedent of the preceding section, in which the trolley wheel and its mounting, which are also part of the car equipment, were dealt with in connection with the trolley wire and not in connection with the car.

The problem is to

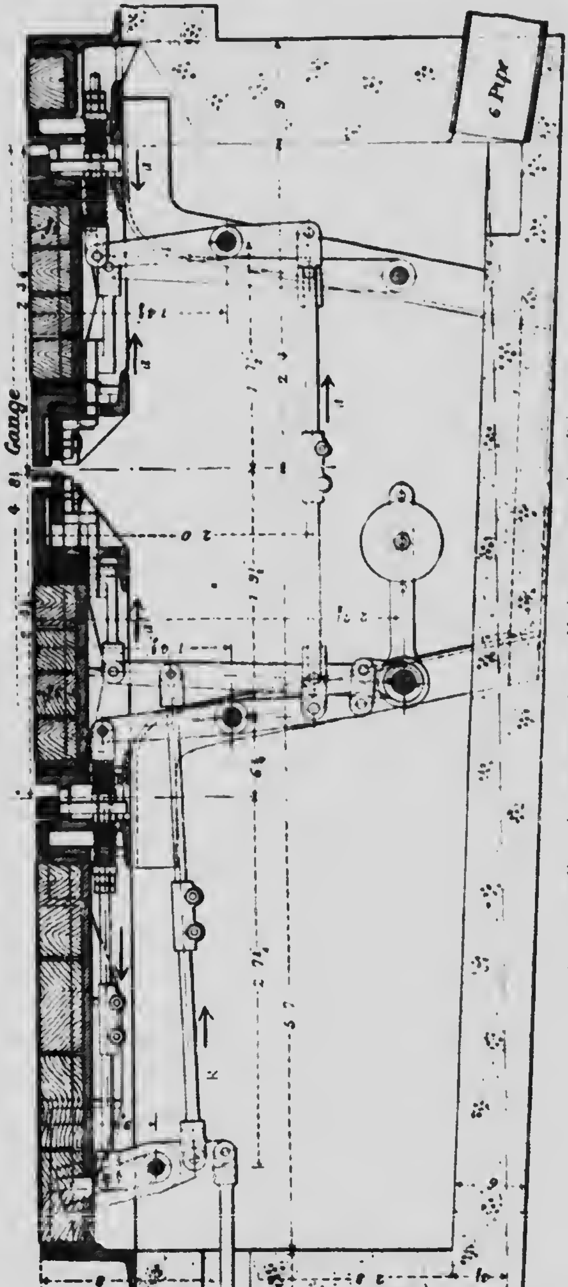


Fig. 1153. Vertical Cross section showing Mechanism at Switching Point

pass from the car two insulated conductors of sufficient cross-section to carry the necessary currents, and sufficiently well insulated from one another and all exposed metal-work to stand a pressure of 550 to 660 volts, through a slot not wider than 1 inch, and in some cases only ¾ inch

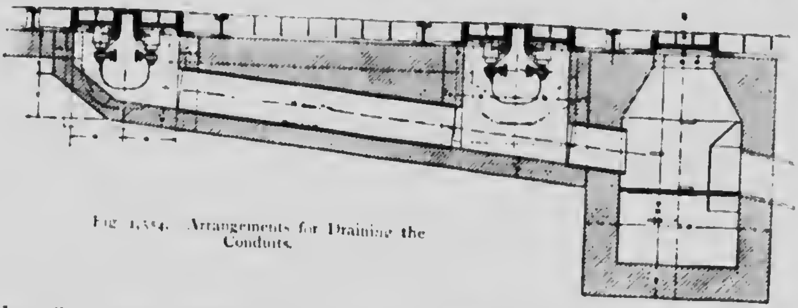


Fig. 1,554. Arrangements for Draining the Conduits.

wide. The design must be substantial enough to stand the rough usage of ordinary tramcar work, and the shank, or solid support, must run easily in the slot without any tendency to jam. Also, the rubbing surfaces must press on the conductors in the conduit with a somewhat elastic pressure, to allow for inequalities in construction and running. The problem is, indeed, more a mechanical than an electrical one, though sound electrical design is vital.

Fig. 1,555. Plough of early Bournemouth Tramways.

As examples of the solutions which have been worked out, Fig. 1,555 shows in perspective the plough used in the early days of the Bournemouth tramways, and Figs. 1,556 and 1,557 give a vertical side view (Fig. 1,557), partly in section, and a vertical cross-section (Fig. 1,556), of a plough, subsequently developed for the London service. The general appearance of such a plough can be well realised from Fig. 1,555. The plough is supported by the lugs L L, on bars passing across the car; it usually has lateral freedom of motion transverse to the length of the car, so as to allow for different positions of the slot relatively to the running rails. The shank S, in which the insulated conductors are embedded, passes down through the slot, after passing which there is room to build up the necessary support for the flexibly mounted plates P, which are to rub against the fixed conductors in the conduit.

In Fig. 1,556, in which the same letters are used to indicate the similar parts, the cross-section is taken through one of the embedded conductors, which is in the form of a strip of copper, seen only in section, passing down through the shank s. The details of the insulation of this conductor, and the methods by which it is brought out at the two ends can be easily made

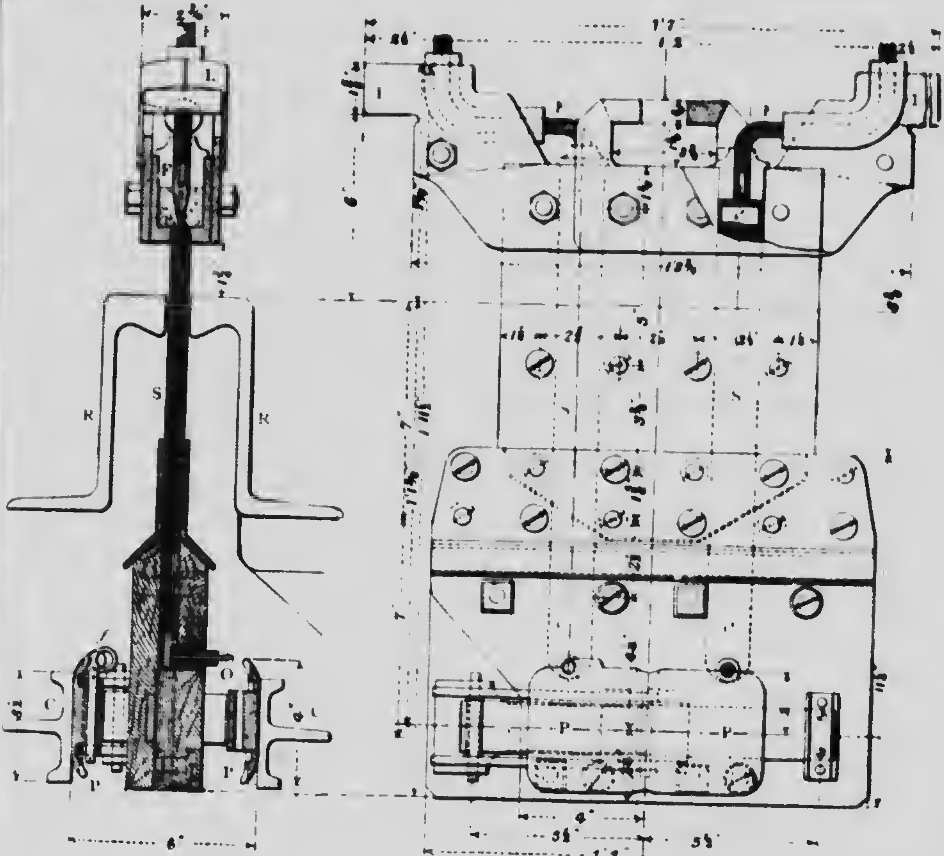


Fig. 1,556. Details of London County Council Plough. Fig. 1,557.

out in the figure. The relative positions of the two conducting strips, fore and aft, are shown at *c c* and *c′ c′*, in Fig. 1,557. At their lower ends connection is made to the rubbing plates P P by flexible conductors *f* (Fig. 1,556), and similarly, at the top ends, connection is made to terminals on the car by heavily insulated flexibles F F, the ends of which can be seen coiled up in Fig. 1,555. In Fig. 1,556 the slot rails R R and the fixed conduit conductors C C are shown in position relatively to the plough. Both this figure and

Fig. 1,557, which are copied from *Engineering*, have all the principal dimensions in inches marked on them, and from these the actual sizes, both over-all and in the details, can be ascertained. The total height is about 24 inches, and the over-all width 19 inches, the width of the shank s s being 10 inches.

Very full details of the 1908 pattern of the plough used by the London County Council are given in Figs. 1,558 to 1,561. In these drawings, Fig

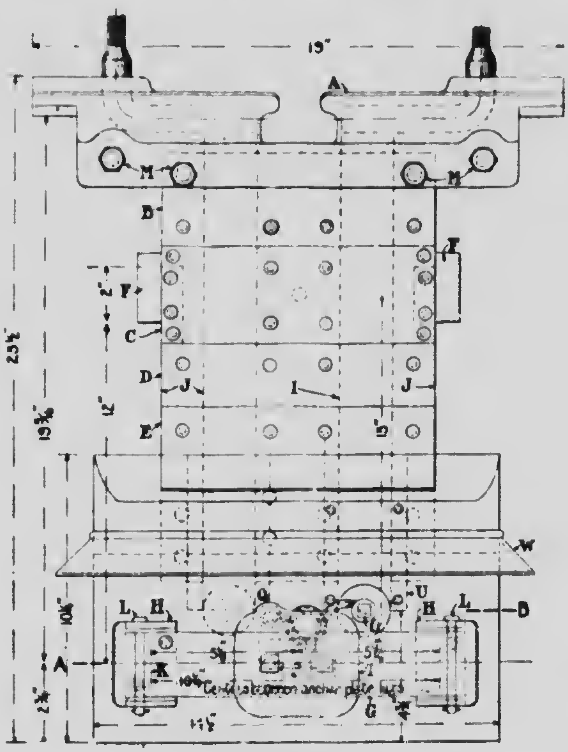


Fig. 1,558.

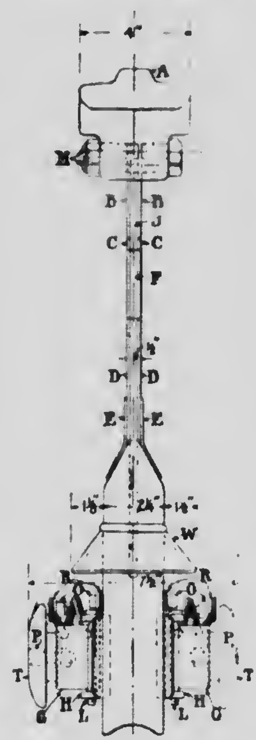


Fig. 1,559.

Side and End Elevations of London County Council Plough (1908).

1,558 is a side view of the plough, Fig. 1,559, a vertical end view, Fig. 1,560 a horizontal view or plan, as seen from above, and Fig. 1,561, a horizontal cross-section in two halves at different levels, the right-hand half through the terminal o (Figs. 1,558, 1,559, and 1,560) of the conductor passing through the shank, and the left-hand half at the lower level of the line A in Fig. 1,558. It will be worth while for the reader to compare carefully this set of drawings with the preceding set (Figs. 1,556 and 1,557), for the purpose of noting points of difference as well as points of resemblance. It would be tedious for us to draw attention to each of these separately, but one or two of the more important may be indicated in passing.

The over-all size and the principal dimensions are practically the same for both ploughs, but in the later plough the shank is, as it were, armoured where it passes through the slot by sheet-iron plates C C, terminating in a wedged-shape prow F F fore and aft, which will enable the plough to enter the slot with more certainty at critical points when run-

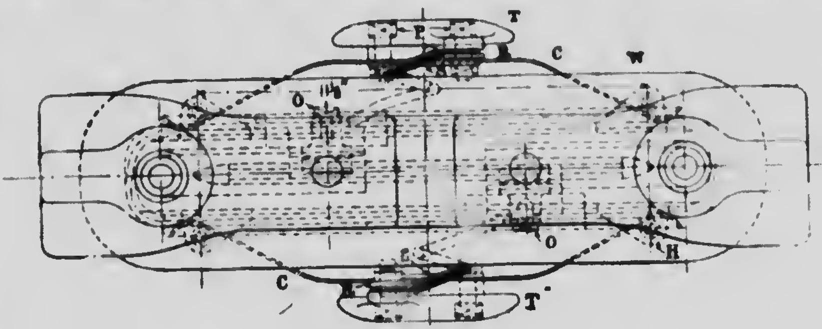


Fig. 1,563.

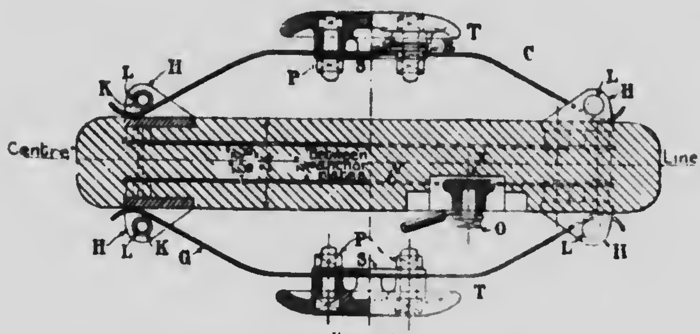


Fig. 1,564.
Plan and Horizontal Section of L.C.C. Plough

ning in either direction. Another important difference is the greater care taken in the later plough with the lower terminals of the vertical conductors in the shank. To appreciate this, compare the terminal O in Fig. 1,556 with the binding post terminal seen at O in each of the last four figures, to which the flexible leading to the rubbing surface can be readily attached, and from which it can be as readily detached. This flexible is also at the other end attached to a well-designed binding post on the back of the rubbing surface, on one of its holding-on bolts. The difference in the details of the rubbing surfaces and of their attachment to the flexible supporting springs should also be noted. Finally, a wide weather guard W, of flexible leather or india-rubber has been added to the later plough, replacing much more effectively the overhanging metal eaves of the earlier one. Other differences will appear on further examination.

A much simpler pattern of plough used on the New York conduits is shown in side view and end elevation in Figs. 1,562 and 1,563. This plough is of about the same width, 14¼ inches, as the English plough, but about 4 inches longer in vertical height. The shank is shielded at the slot level by plates F F, and after the foregoing descriptions, the reader will have no difficulty in understanding its details. The main idea in the design was cheapness, with the deliberate intention of scrapping any ploughs which developed defects in practical use, instead of troubling to repair them. The simplicity (and crudeness) of the method of support by rods passing through holes in the shank is particularly noticeable.

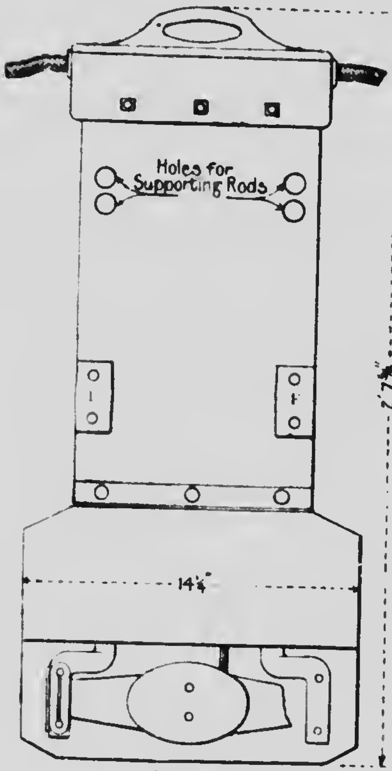


Fig. 1,562

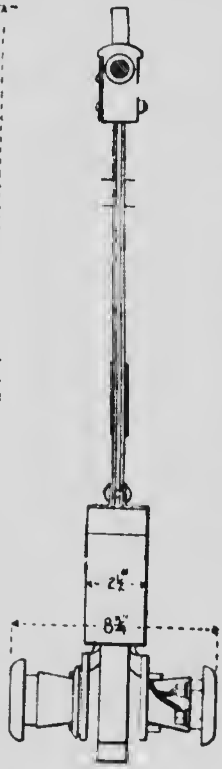
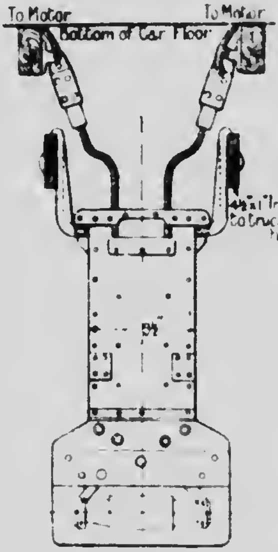


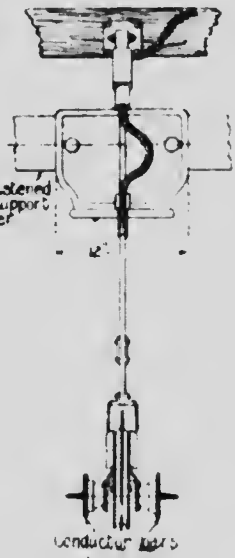
Fig. 1,563

New York Plough [illegible]

A much more carefully designed plough, subsequently made for use in Washington, is shown in Figs. 1,564 to 1,566, which give three separate views. Here again, very little description is needed as the drawings are self-explanatory, but attention may be drawn to the substantial character of the arrangements made, in this case, to support the plough by means of strong hangers securely attached to it, and hanging-over rods of 1-inch iron, 4½ inches deep, fixed to the truck of the car.

Plough Hatches.—The reader will now have a fair idea of the various forms of plough which have been used in actual practice, but an examination of the drawings given will at once suggest that the apparatus illustrated cannot be introduced into the conduit, or, what is as important, withdrawn from it in case of accident, through the ordinary slot, and therefore some special arrangements are necessary for the purpose, at not too great distances apart. The usual method is to place at suitable intervals ***plough hatches***, as they are called, one of which can be seen, quite open in Fig. 1,544. At these points the slot gives place to a much wider rectangular opening between the fixed rails. This opening has ledges projecting inwards from its bottom edges, and on these rest the two heavy hatches which close the opening when it is not required, and leave between them at the road surface the clear space of the ordinary slot. The hatches are, of course, so designed that they are not likely to be disturbed by the ordinary traffic.





Much fuller details of a plough-box or hatch are shown in Figs. 1,567 to 1,571, which also show the break in the conductor rails at the end of a working section, and how the "feeder" leads are brought to the conductor rails on each side of the break.

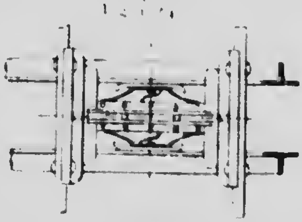
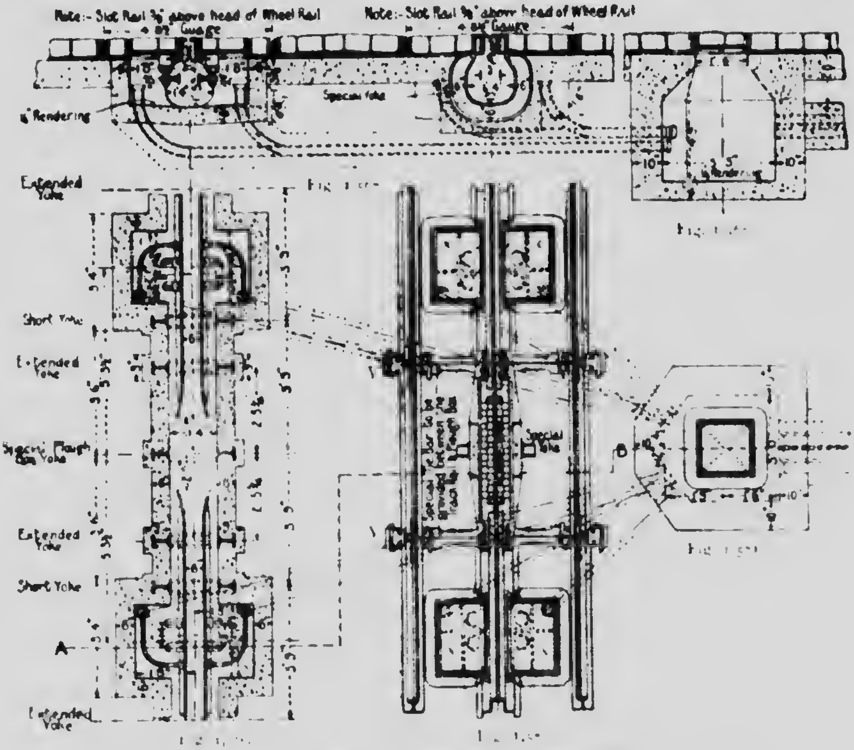


Fig. 1,569 is a horizontal section at the level of the conductors in the conduit; Fig. 1,570 gives the general ground plan whilst Fig. 1,567 is a vertical section along the broken line AB in Figs. 1,569 and 1,570. The pit 30 inches wide and 57 inches deep from the road level, shown in Figs. 1,568 and 1,571, is to facilitate the manipulation of the feeders, and for testing purposes; there is probably a feeder column close at hand. From this pit flexible cables + and —, are led through pipes (shown by dotted lines to each of the four insulation boxes X X X X on the up and down lines on either side of the break. The plough hatch is situated right over the break in the conductors, so that when the plough is dragged to the hatch it swings clear of the conductors, and is, of course, dead, and may be safely handled. The break is 24 inches clear, and the ends of the conductors are splayed outwards, so that the rubbing surfaces of the plough may, as it moves along, engage with them without shock. Extended yokes Y Y are used at either end of the plough-hatch, and a special yoke at its central part. Other interesting details can be made out from the figures which give most of, if not all, the important dimensions.



Details of Plough Hatch [illegible]

Changing Over. It has already been explained that the conduit system, on account of its costliness, is not so widely used as the overhead trolley. In modern developments the tendency is to extend electric tramways from towns and suburban districts along the roads, connecting one town with another, and thus gradually to cover the whole area of a large industrial district. It thus happens that cars which are provided with ploughs for conduit working inside a city are required to run many miles outside, where the overhead trolley only is available. It is therefore necessary to provide some method of changing rapidly from one system to the other without disturbing the passengers, for any necessity for the latter to "change cars" would kill a great part of the traffic. This requires that each car should be fully equipped on the one hand with at least one trolley

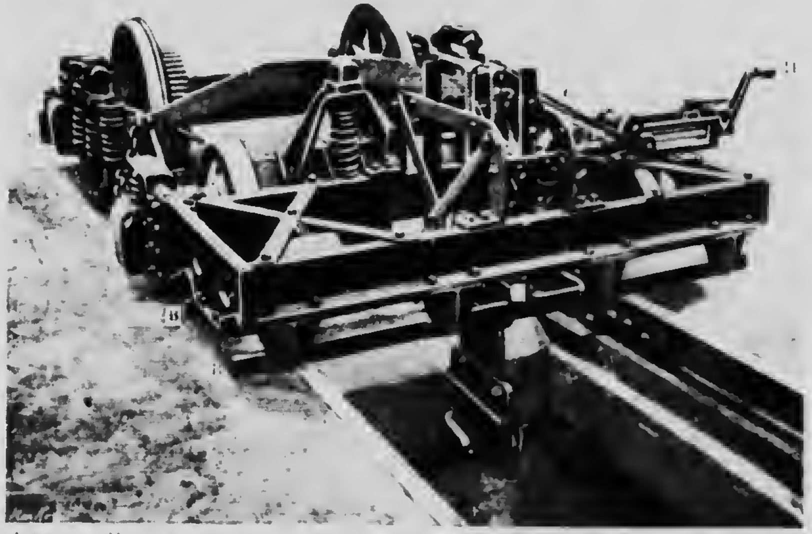


Fig. [illegible].—Mechanism for Raising a Plough out of the Conduit without Detaching it from the C[illegible]

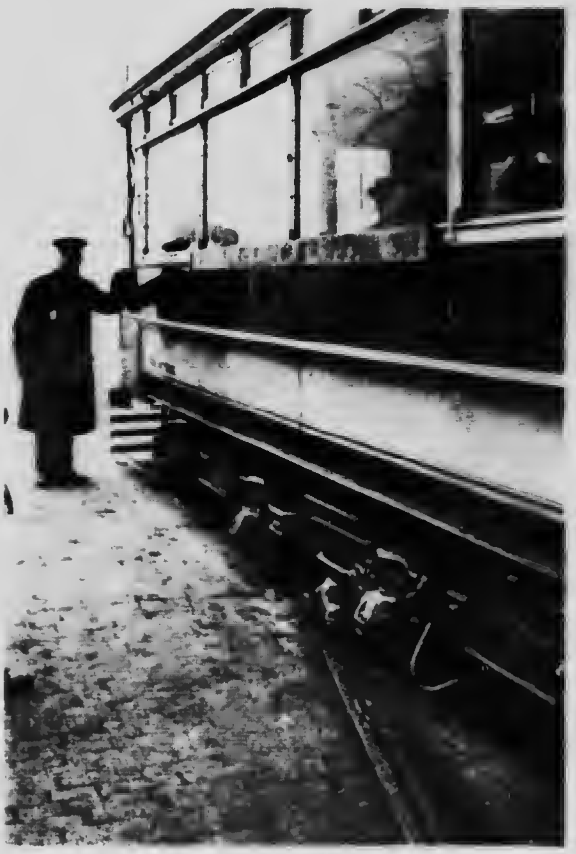
pole and its fittings and supports, and also with arrangements for carrying a plough or ploughs. These must be provided with the proper main elements, and there should be a change-over switch for use when changing from one system to the other.

The disposal of the trolley pole when the plough is in use is a comparatively simple matter. It can be readily and securely clamped down in a horizontal position. For putting of the plough out or [illegible] whilst the trolley is being

[illegible]

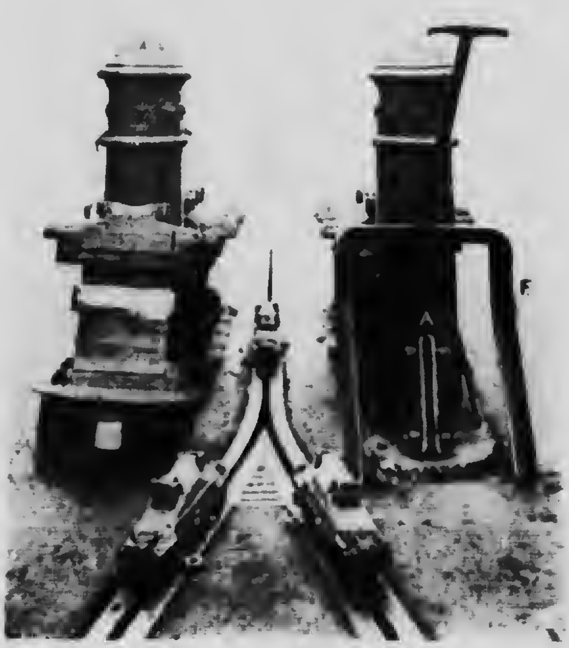
used is not so simple. Two general methods are obviously possible: one being to raise the plough out of the conduit, carrying it always on the car, whether in use or not; and the other is to remove the plough from the car at the end of the conduit line and pick it up again on the return journey.

At first the former of these methods was adopted, as it was thought that the latter necessitated an expensive and roomy manhole between the rails at the transition point, with a man in attendance to remove and replace the ploughs. Devices were therefore invented for raising the plough rapidly to a position under the body of the car and clear of the road. In Berlin the plough was equipped with a wheel at its lower end, which ran up an inclined plane at the changing spot until it reached the level of the wheel rail along which it ran and the plough was then further raised by the driver giving a single turn to a crank. The contact shoes were fixed on horizontal axes, and were able to pass through the slot by being depressed to a vertical central position. The device has the obvious disadvantage of very much complicating the design of the plough.



[illegible] Plough

In Paris and in Brussels the plough was lifted by mechanism on the car through an ordinary plough hatch placed at the conduit terminus where such a hatch would ordinarily be placed for other purposes. These devices were used on the Continent before the close of the last century, and similar ones were employed in England still more recently. The method that was adopted at Bournemouth, for instance, is shown in Fig. 1572, in which the plough is seen lowered into a pit between the rails close to the end of the conduit, which, however, is not shown. The plough is raised and lowered by chains C, passing over pulleys, and attached to a sliding block, operated by the handle H working a screw and travelling nut. By this means, the car having been brought over the pit, the plough can be raised or lowered as may be required with no more delay than is involved in bringing the trolley wheel on to the overhead wire, or removing it therefrom and anchoring it. In its lowest position the lugs L of the plough rest upon transverse bars B B, on which the plough can slide transversely for the whole width of the running rails.



[illegible]

The other principle, namely, that of detaching the plough entirely from the car at the change-over, was subsequently adopted in London, and offers a much more simple solution. For this purpose the plough when in use in the conduit, rests, supported by its lugs, on transverse bars similar to those shown at B B in Fig. 1572. On these bars it can travel from side to side of the car across its whole width, as may be rendered necessary by any varying position of the slot, an arrangement which has advantages, as already mentioned, for purposes other than that now being considered. At the place where the change has to be made the conduit and the slot are deflected as shown in Fig. 1573, where the left-hand track is the one for an outgoing car from which a plough is to be discharged, and the right-hand track is for an incoming car for which a plough must be provided. A car going outwards on the left hand track, having first been connected to the overhead trolley, will, by the deflection of the conduit, have its plough brought across to the right, outside the running track where it would drop off the ends of the bars B B (Fig. 1,572) on to the slot rails were it not that a little four-wheeled trolley seen somewhat dimly at *a* in Fig. 1,573, is placed ready to receive it. The little trolley receiving the plough is shown clearly in Fig. 1,574, and is again shown without a plough and on an enlarged scale at X in Fig. 1,575. It will be noticed that if it be placed a little in front of the dropping-off point *a* (Fig. 1,573) the stem of the plough will engage with the horizontal U of the trolley and push the latter before it until it drops upon it. Fig. 1,575 also shows, on an enlarged scale, the junction between the "down" and "up" conduits with four ploughs on their trolleys waiting to be transferred to incoming cars. It also shows some spare ploughs resting against the left hand column and beyond the junction in the short extension of the conduit there will [illegible] a plough hatch [illegible] enables damaged ploughs to be withdrawn and replaced by good ones. The ploughs are obviously hauled along this short length of conduit by hand, by means of a hook inserted in the eye-bolt seen at the side. It is difficult to imagine anything simpler than this system of getting rid of the plough.

Fig. 1,576. Incoming Car picking up a Plough

The method of picking up the plough by an incoming car is almost equally simple. For this purpose the car is stopped so that the transverse bars B B (Fig. 1,572) are opposite some point on the short parallel strip of conduit S, Fig. 1,573, to which also a spare plough has been drawn. An attendant than inserts the fork F, Fig. 1,57[illegible] under the outer lugs of the plough, and rests the ends of the fork on supports provided on the car. The car then travels forward with power derived from the overhead line and the plough is drawn inwards, as seen in Fig. 1,576. On reaching the frame of the car the plough is raised off the little four wheeled trolley to the proper level by the attendant, and slips into its place on the supporting bars, simultaneously making sliding contact with fixed conductors on the car, and almost immediately engaging with their conductor rails in the conduit. The change-over switch on the car is then thrown over, transferring the connections from the trolley pole to the plough, and the transfer from trolley line to conduit rails is completed.

IV. SURFACE-CONTACT OR CLOSED-CONDUIT SYSTEMS.

In the "summary of methods" (see page 1383) the third place is given to the method in which "contact is made by a sliding skate or bar underneath the car with a series of surface contacts placed at short intervals, usually between the rails, and connected as required to live conductors in *closed conduits* in the neighbourhood of the track." This describes quite clearly the general method, which has the advantage over the open-conduit system just described that the conduit is not open to receive from the street the water and dirt which find their way into the conduit through the slot. On the other hand it has disadvantages, some of which will appear in the sequel.

In the last decade of the nineteenth century and the first decade of the present, many systems were invented to provide practical surface contacts suitable for ordinary tramway traffic. Some of these systems were actually laid down in commercially operated electric tramway schemes; others were advanced so far as to be tried on short experimental tracks, whilst others never got beyond the drawing-office and patent-office stages. At the present day none of these is in use to a sufficient extent to justify occupying the limited space at our disposal with descriptions and illustrations of its details. It will, however, be of interest for purposes of record and future developments to summarise and classify the systems which reached, or still occupy, a position to make them worthy of such attention. It is, of course, not claimed that the summary is exhaustive.

Before summarising, however, it will be convenient and enable the reader to follow more clearly the practical points involved, if attention is directed to one or two of the principal outstanding conditions which should be satisfied if the system under consideration is to be used on highways and roads open to general traffic. The most important is that the surface contacts on the surface of the road must not by projection or otherwise be mechanically dangerous to other traffic. Thus the necessary projection to ensure contact with the slider on the car must be reduced to a minimum; also the road contact pieces should not extend to metal plates so large that iron-shod horses would be likely to slip on them.

In order that the reader may understand the importance of this point, and be given a general idea of the appearance of a surface-contact system, as it presents itself to the man in the street, Figs. 1577 to view of the suburban terminus of a tramway installed on the Diatto system in Tours. Similar installations were made in Paris and other French towns. The contact studs, which were of cast-iron, can be seen between the running rails, where they appeared as metal plates about 15 feet apart.

The next very important point is that electrically the road contacts must only become "alive" when the car is over them or so close that other traffic is not likely to be endangered. The results of the iron shoe of a horse coming into contact with a stud at 500 volts, with the power of a generating station to draw upon, have led to highly imaginative articles in the daily press. The system must therefore be so designed that the

Fig. 1178.—A Surface-contact Tramway in France

studs only become electrified when an oncoming car is within a certain short distance, and also become "dead" as soon as the car has passed.

Another electrical requirement which, if not satisfied, would lead to trouble, is that the skate or slider must always be in contact with a "live" stud whatever the position of the car. The necessity for this is obvious, and the practical outcome is that the studs must be closer together than the length of a slider, so that the latter is picking up energy from a forward stud before it breaks contact with the stud behind. The length of the slider, which has obvious limitations for other reasons, thus fixes a maximum and somewhat short limit to the distance apart of the studs.

Summary of Systems.—Bearing these and other requirements in mind, the most convenient method of dealing with the systems to be mentioned is to divide them into two main classes, which we shall call (*a*) *magnetic* and (*b*) *electro-magnetic*. In the first, the *magnetic* class, the switching device depends upon the effect produced by the magnetic field or fields of permanent or electro-magnets carried on the car, or on the slider upon magnetic material under the surface of the road when the car is brought near a contact piece. In the *electro-magnetic* class the switching is done by electro-magnets in the conduit or below the surface of the road, the circuits of these electro-magnets being controlled by apparatus carried by the car. The following is the summary:

(*a*) *Magnetic Systems.*

(i.) A chain conductor lying in a closed conduit just below the surface of the road and lifted into contact with the lower parts of the studs when the car comes over them. (Methods of carrying out this idea have been patented many times.)

(ii.) Systems using levers tilted by the moving magnetic field and closing contacts when the car comes over, the contacts being opened by the action of gravity when the car has passed. (This idea has also been fruitful of patented inventions.)

(iii.) Contacts made by the lifting of an iron plunger floating vertically in a tube containing mercury, the plunger falling and breaking contact when the car has passed. Systems (the Diatto, Fig. 1,577, and others) of this type have been used commercially in Paris and other French towns.

(iv.) Systems (the Dolter, used in Hastings, etc.) similar to (iii.) but discarding the mercury and the iron plunger for a nearly balanced hinged armature. A further modification (the Lorain) was used in Wolverhampton on a track eleven miles long.

(v.) The "G.-B." (Griffiths and Bedell) system, used in Lincoln and for a short time on a small section in the East End of London. A line conductor of stranded iron cable was laid resting on insulators in stoneware pipes, and a piece of laminated iron suspended by springs and in conducting connection with the road stud was drawn into contact with the live cable when the car approached or came over the stud.

(*b*) *Electro-magnetic Systems.*

These systems make use of electro-magnets, usually of the solenoid or plunger type, the circuits of which are closed and opened either directly or indirectly, by the slider as it moves over the surface contacts. The movement of the armature or plunger usually closes a main line contact, which brings a particular surface contact into circuit or breaks such circuit when the car has passed. The more prominent systems which have been developed are the following, the chief differences being in the design and position of the electro-magnets and the arrangements of the circuits, which make it difficult without diagrams to do more than tabulate the systems.

(i.) *Dr. S. P. Thompson's* system, which was tried on an experimental track only; a well-designed electro magnet with ingenious details for ensuring the closing and opening of the main circuit and minimising sparking difficulties. A single row of studs was required.

(ii.) The *Schukert* system, laid down in Munich in 1899, also required only a single row of studs, but the switching arrangements necessitated the studs being placed so close, or the slider being of such a length, that the latter could be in contact with not fewer than two and usually three studs simultaneously. Each electro-magnet had forward and backward circuit connections with other magnets, so that in addition to the main conductor, no fewer than six other insulated conductors had to be run the whole length of the track. There were two electro-magnets and three pairs of contacts for each stud, and the wiring was very complicated.

(iii.) Other systems require two rows of studs between the rails, and therefore two sliders rigidly connected together on the skate but electrically insulated from one another. One example is the *Westinghouse*, in which the two studs are side by side on the track, and the electro-magnets are wound with series and shunt coils. The power-current contacts and the magnets are contained in a switch contact box, with conductors to the studs and the live cable.

(iv.) A very similar system is the *Helios*, which, with other differences, has as many as eight magnets, for eight successive pairs of studs, gathered together in one contact box.

(v.) Another example is the *Thomson-Houston*, used at Monaco, in which the double contacts are staggered, the contacts of one row being half way between those of the other row. One row, when energised, is at the full voltage of the supply conductor, the other row being connected to the other pole of the motor nearly at earth potential; it is from this low-voltage row that the switching electro-magnets receive their current. A three-way contact is made when a magnet is energised.

(vi.) Still another class makes use of an almost continuous third rail, between the running rails, instead of studs. An example occurs in a system designed by *Dr. John Hopkinson*. A contact maker runs along the third rail and carries a backward and a forward contact, insulated from one another, and so spaced in relation to the length of the sections of the third rail that usually one contact is on one section and the other on the next. The sections become successively alive by currents from circuits closed in the contact boxes, of which there is one for each section of the rail.

(vii.) A final example, the ***Johnsen-Lundell***, has a single row of studs between the rails and a sectioned third rail outside the running rails. The car carries a long slider to make contact with the studs, and a travelling brush to make contact with the third rail, each section of which is double the length of the distance between the studs. The switching magnets, one for each stud, are double-wound, one coil being in series with a coil of the magnet in front, and the other with a coil of the magnet behind.

The above summary is far from exhaustive, but it is hoped that it will give the reader some idea of the systems which have been devised to replace the overhead trolley and the open-conduit systems, as well as of the great amount of inventive skill which has been lavished on this problem.

V. TELPHERAGE

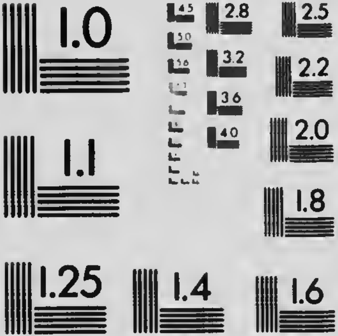
An application of the conveyance of electric energy to a moving system by overhead conductors, which dates back to the early days of electric

Fig. 1,578 Glynde Telpherage Line.

traction, is not without interest at the present time. In its earliest commercial forms it was elaborated by Professors Fleeming Jenkin, Ayrton and Perry, and was named *telpherage* by its first projectors. The over-

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



head conductor conveying the electric energy also supported the moving and weight-carrying devices, thus dispensing with the rails of a tramway system and freeing for other purposes the ground they occupied.

Fig. 1,579.—A "Coke Telpher" at the Warrington Gas Works.

This early system was fully described in the 1893 and earlier editions of this book, from which Fig. 1,578 is reproduced to give a general idea of the appearance of one of these early telpher lines. A full description will be found at pages 701 *et seq.* (1893 edition), including details of several of the ingenious devices employed for automatically controlling the supply of current to the motor on the moving train of skips and regulating the speed. The overhead track, which was used in connection with a cement manufacturing works, was nearly a mile long, and the overhead conductors and carriers were steel rods ¾ inch in diameter.

The rapid development of electric traction on roads at about the period when telpherage was being introduced was probably one of the causes of it being neglected for some years, but of late it has been revived in a modified form, and there are now numerous installations in these islands and abroad. We therefore shall refer briefly to this modern apparatus and equipment.

In the present-day systems the simple and overhead rail, acting as both supporter and conductor, is replaced for supporting purposes by a rigid monorail overhead track, the erection of which is considerably more costly than the track shown in Fig. 1,578. This will be realised by an inspection of Fig. 1,579, which gives a view of a "coke telpher" at the Warrington gas works, erected by Messrs. Strachan and Henshaw of Bristol.

In these "telphers," as they are now called, unlike their prototype, an attendant to direct and control the work is carried with the travelling

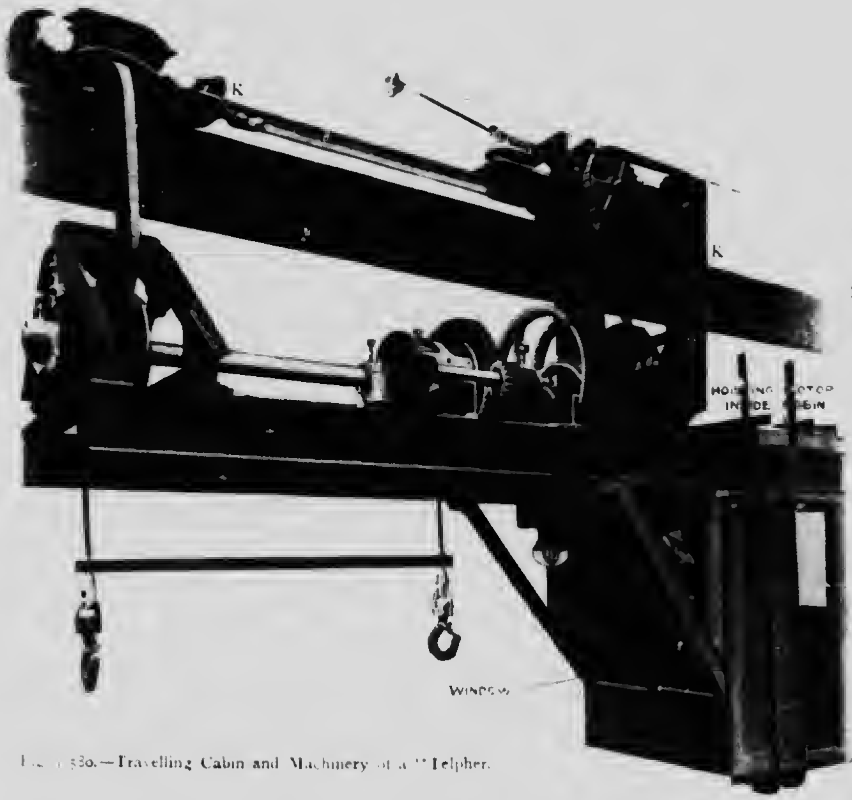


Fig. 1,580.—Travelling Cabin and Machinery of a "Telpher."

skip or other load container. This travelling machinery, etc., which can be seen at the near part of the track in Fig. 1,579, is shown on an enlarged scale in Fig. 1,580, where T T is part of the monorail track supported as shown in Fig. 1,579. On this track there run two free-swivelling bogie trucks K and K, each carried by a pair of manganese steel wheels in tandem, the axles of the wheels being carried on roller bearings. The driving motor, controlling cabin, and any other gear required for the particular work in hand, are supported, below the

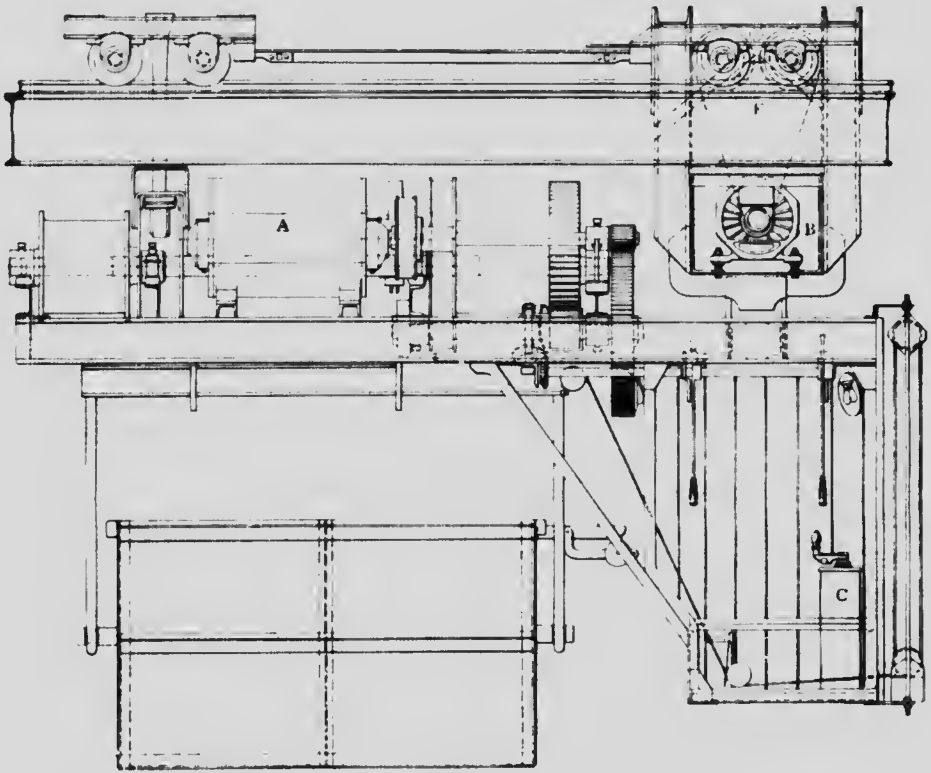


Fig. 1,581.

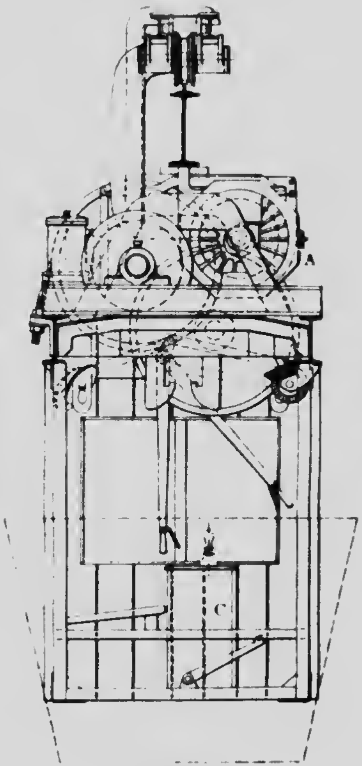


Fig. 1,582.

Fuller Details of the Machinery of a "Telpher" fixed rail, from the framework of the trucks on a suitable platform, which in Fig. 1,580 is provided by a couple of **H** joists carried horizontally below the track.

Full details of a very similar equipment, drawn to scale, are given in Figs. 1,581 and 1,582, the chief difference between the two equipments illustrated being in the position of one of the electric motors. In both there are two such motors, one B carried below the forward bogie K and driving it by chain gear as shown clearly in Figs. 1,580 and 1,581; this is the telpher motor proper, and corresponds to the motor used in the early telpher (Fig. 1,578). The particular purpose for which the modern telpher illustrated is used is that of a travelling crane, and therefore a second motor is installed to act as a hoisting or lifting motor. This motor in Fig. 1,580 is carried in the cabin and is not shown in the figure, whereas in Fig. 1,581 it is the motor A carried on the platform above the cabin,

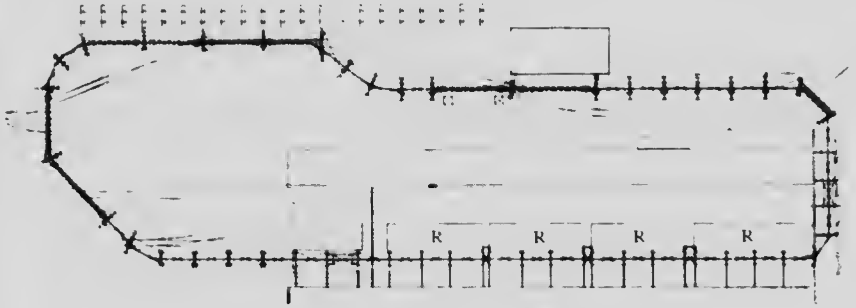


Fig. 1,583.—Plan of the Warrington "Coke Telpher."

and drives the shaft of the two hoisting drums through suitable double-reduction gears.

Both motors receive current from an overhead conductor, which can be clearly seen in Fig. 1,580, by means of a trolley wheel or a slider carried on a suitable trolley pole mounted on the front bogie truck. The return circuit is through the running rail, to the supporting beam of which the — pole of the supply leads is connected at a convenient point. The current from the insulated conductor is carried to the controller C (Figs. 1,581 and 1,582), which is of the ordinary cylindric type described elsewhere in this book, and the attendant sitting or standing in front of the controller has within reach of hand or foot all the necessary controls.

Returning now to the view of the Warrington installation depicted in Fig. 1,579, a plan of the plant is given in Fig. 1,583, from which it will be gathered that the rail forms a closed track, which at one part passes through the retort houses R R, in which the coke is taken direct from the retorts, and then over suitable quenching tanks into which the hot coke can be lowered before being carried to the storage hoppers or loaded direct into carts or railway trucks in convenient positions. The whole track is 1,300 feet long, and arrangements are made by switches for additional lengths of track to be added so as to reach the other parts of the works. One of these off-shoots, not shown in Fig. 1,583, can be seen on the left-hand side of Fig. 1,579. Each of the motors used is a 12-H.P. continuous-current motor, supplied with current at 220 volts; the maximum speed of travel is 600 feet per minute, or 6·8 miles per hour, the lifting capacity being 35 cwt., and the maximum hoisting speed 70 feet per minute.

Various patterns of telpher machines have been standardised for different classes of work by Messrs. Strachan and Henshaw, and by other firms, and their use is by no means confined to handling the materials in the manufacture of coal gas, though up to the present the greatest part of the development seems to have been in that direction. It would be interesting if some of the earlier applications could be revived with modern electrical appliances and with the experience of the past twenty-five years as an additional guide.

VI.—SECONDARY BATTERY SYSTEMS AND METHODS

The three first sections of this chapter dealt with the principal methods adopted for conveying electric energy from the generating or the substation to the moving vehicle by means of fixed conductors, from which the energy is to be picked up by the vehicle as it moves along the prescribed route marked out by these conductors. We turn now to the systems referred to on page 1383, in which the energy is carried by the vehicle in some form in which it can readily be made available as electric energy for use in the driving motor or motors.

To the electrical engineer the most interesting form in which it can be carried is that of the chemical energy of a secondary battery, and some of the secondary cells described in Chapter IX have been specially designed or modified for use in electric traction.

The **Lead Secondary Cell,** which has played such an important part in more than one sphere of electrical development, is seriously handicapped, when applied to traction work, by its heavy weight per unit of electric energy stored; and, as explained elsewhere (*see* page 1064 *et seq.*), one of Edison's chief objects in developing the nickel-iron secondary cell was to obtain a lighter type of cell for traction purposes. It is obvious that for such purposes dead weight, which is comparatively unimportant in stationary batteries, becomes of vital importance, since it increases the dead or unproductive weight of the vehicle, be it road vehicle or tramcar, and *pro tanto* diminishes the carrying space or the maximum useful weight which can be carried. The various considerations which have compelled manufacturers to develop every method of reducing the weight of stationary lead cells are intensified when the cell is to be used as a source of energy on a moving vehicle, in which it has to be carried as a load which, as such, has no freight-earning capacity.

Some of the lead secondary cells described in Chapter IX. represent solutions of the problem of the adaptation of the lead cell for traction work. More particularly is this the case with the "Ironclad Exide" cell, the unusual form of the + of which is described on pages 1023 and 1024. The reduction of total weight, by reducing the weight of the individual plates per unit of energy stored, has probably been carried as far as desirable, or even practically possible, with all types of lead cells; and in this connection it must not be overlooked that the conditions of service are in traction work much heavier than in ordinary stationary work, and that therefore these conditions militate against the use of frail or dangerously unsubstantial plates. The other directions available for reduction of weight lie in the details of the necessary accessories, such as containers, separators, connectors, etc.

As regards the arrangement of the plates and the size of the boxes or containers, overall dimensions which are not unimportant for other purposes are of paramount importance when space has to be found for the battery on a moving vehicle, and great attention has been paid to these points. Some of the cells illustrated on pages 1038 to 1040 exhibit the results attained where, for other purposes, similar conditions exist, and in Fig. 1,584 there is shown the "Ironclad Exide" cell as designed for electric vehicles by the Chloride Electrical Storage Co. Part of the casing and part of the end — plate have been cut away to expose the internal plan of the cell, and it will be noticed that there is very little lost space in any direction. The containers are boxes of thin ebonite of a length, at right angles to the plates, depending on the number of plates in the particular cell and only just sufficient to hold these plates comfortably. The plates are supported on ebonite grids which form part of the box, and are designed so as to leave ample space below the plates for the accumulation of sediment, in order that the cells may be in use for long periods without requiring to be cleaned out. Each cell is fitted with an ebonite cover,

Fig. 1,584.—An "Ironclad Exide" Lead Secondary Cell.

through which the electrodes pass and in which there is a vent-hole closed by a soft rubber plug. The cover can be ea[illegible] removed for inspection or testing p[illegible]s.

Fig. 1,585.—A "Super-Exide" Cell.

The [illegible] shown ex[illegible]sed in Fig. 1,584 are of the special type described fully at page 1024, and it is claimed that these cells have, for traction work, a useful life two to three times that of an ordinary flat-plate accumulator, that they are very reliable, and give a reasonable mileage. Moreover, they can be charged when necessary at higher rates than the flat plates. They are not, however, particularly light for their capacity, and if a lighter cell occupying the minimum of space for its output is required, the cell shown in Fig. 1,585 is used. This is known as the "super-exide" cell, and has [illegible] of the type described on page 1021 (Fig. 1,040). As showing the difference between the two types, it may be mentioned that the cells of Fig. 1,584, having a capacity of 100 ampere-hours on a five-hour discharge, are 5 in. long, whilst those of Fig. 1,585 are only $4\frac{1}{2}$ in. long, a difference of 10 per cent., both cells being $6\frac{1}{8}$ in. wide. Also a battery of forty cells of the first type weighs 1,680 lb., whilst a similar battery of the latter weighs only 1,470 lb., being thus $12\frac{1}{2}$ per cent. lighter. The

Fig. 1,586.—Tray of Ironclad Exide Cells.

latter cells, however, require $1\frac{1}{2}$ in. more head room, being $15\frac{1}{2}$ in. high against 14 in., the overall height of the former.

The cells of the shape shown required to form a battery can obviously be compactly assembled in a suitable box, with the terminals to be connected at a minimum distance apart. Such a box or tray, containing six Ironclad-Exide cells, is shown in Fig. 1,586. The cells are 17 plate cells having a capacity of 300 ampere-hours on a five-hour discharge; the tray is 46 in. long by $7\frac{1}{2}$ in. wide by $14\frac{1}{4}$ in. high, and with the cells weighs 370 lb. The connectors used are thin strips of copper, plated with lead to avoid corrosion; the ends of the copper are cast into alloy terminals, which form a ring fitting over the pillar of the plate-connecting strap into which the ring is burned. In this way the resistance of the connecting link from cell to cell is reduced to a minimum.

Fig. 1,587.—A "Can-Trac" Lead Secondary Cell.

The external appearance of the special cell for vehicle traction, manufactured by the Hart Accumulator Company, is shown in Fig. 1,587. The plates [illegible] this firm have been fully described [illegible] IX. The feature of the traction, o[illegible]rac" type of cell, is its compactness and [illegible]ability, as well as its lightness. A cell having an output of 190 ampere-hours on a five-hour discharge is $4\frac{1}{8}$ in. long by $6\frac{1}{16}$ in. wide by $11\frac{3}{8}$ in. high, and weighs 31 lb.

All lead traction cells are necessarily well sealed, except for a vent carefully designed to allow of the release of the gases which may be generated if the cell be improperly handled during charge or discharge, and the pressure of which, if they were allowed to accumulate, would eventually burst the containing vessel and put the cell out of action.

The **Nickel-iron Secondary Cell**, which has been specially developed for traction work, has been fully described at pages 1064 to 1075, and therefore no further description is necessary here.

In view of the unpromising nature, both physical and mechanical, of the principal material used, the manufacturers of lead secondary cells have achieved remarkable results, which will bear comparison with the corresponding results obtained by the designers of the nickel-iron secondary cells. The following figures, supplied in each case by the makers, are given for a Hart "Can-Trac" cell and an "Edison" cell respectively, the cells selected having about the same output of energy under working conditions:—

TABLE XXIII. COMPARISON OF LEAD AND NICKEL-IRON TRACTION CELLS

	Hart "Can-Trac"	Edison "Nickel-iron A-12"
Number of plates	17	23
Ampere hour discharge capacity	310	504
Average voltage	1·96	1·2
Watt hour capacity	608	610
Weight in lbs.	46	41
Over-all size	6" × 6"·44 × 11"·44	7"·37 × 5"·50 × 14"·62
Horizontal section (sq. ins.)	38·6	40·5
Energy efficiency (per cent.)	74 (p. 1048)	60 (p. 1072)

It will be noticed that the lead cell, whilst 12½ per cent. heavier than its nickel-iron rival of equal output, occupies less space, both in the vertical and the horizontal direction, and that it has an energy efficiency 1·3 times greater. The table does not cover all the points which should be taken into account, but it suffices to show that the two types run one another in some important respects very close. The efficiencies given however, are efficiencies deduced from experiments on cells only. Under working conditions the actual efficiencies will be appreciably lower. For instance, in some recorded tests the efficiency in electric automobile work of an "Exide" battery was found to be 70 per cent., and that of an Edison battery of equal output was 46 per cent.

VI(i.).—BATTERY TRAMCARS

In the last decade of the nineteenth century and the beginning of the present century there was a fair number of tramway systems in the United Kingdom, and more especially abroad, in which the energy was supplied to the motors from secondary batteries carried on the car. The batteries were usually placed in convenient receptacles under the longitudinal side seats which are common to this type of vehicle, and in this position they not only occupied space which was not required for any other purpose, but were accessible at a convenient level from the outside of the car without disturbing the passengers. Chiefly owing to the development of the overhead trolley system, as well as to the development of non-electric methods of haulage and locomotion, the battery tramcar has been to a great extent superseded, but it is possible that it may be revived in the not distant future. Whilst, therefore, it is not necessary to devote much space to it at the present time, it is considered desirable to give our readers a general idea of the appearance of the cars and the methods of working.

The appearance of a "battery" tramcar, as will be gathered from Fig. 1,588, is not very different from that of an open or closed-conduit car, inasmuch as there are no visible means of propulsion. The car shown in the figure is a light single-deck, single-truck car, but it will be understood that batteries have been used for propulsion with all the various types of car-bodies. The appearance of the road itself, of course, does not offer, as in either of the other cases mentioned, any clue to the source of energy, inasmuch as the track is an ordinary two-rail tramway with the rails probably somewhat heavier than they are when laid for horse-drawn cars. There are, in addition, no difficulties at crossings or junctions other than those which arise in ordinary railway practice. The cost of equipping the road is therefore very appreciably less than in the other three systems; and, moreover, the loss in the transmission of the electric energy through the feeders and the line conductors is non-existent. On the other hand, each car has to be provided with a somewhat costly working battery, and at least one spare battery, which should be undergoing charging whilst the other is

Fig. 1,588.—Tramcar Propelled by a Secondary Battery.

discharging. Moreover, against the inefficiency of transmitting the energy by feeders and line conductors has to be set the loss of energy due to the inefficiency of the secondary battery, for which figures have been given in Chapter IX. Also against the maintenance charges for the upkeep of the line conductor and its accessories in the other systems there must be set in the battery-car system the averaged cost of the renewals of the cells, and also the cost, including capital charges, of handling the cells in removing them from and replacing them in the cars and during the period of charging. It will thus be seen that, as in most engineering problems, there are advantages and disadvantages on both sides, and that the ultimate choice of a particular system for a particular case must depend upon the estimation and careful consideration of all the circumstances.

Apart from the interest in the secondary batteries themselves, one of the most interesting matters in connection with battery tramcars is the design of the plant required for recharging the batteries, removing them from the tramcars when discharged, and replacing the charged battery on board the car. In the systems which have been in practical use, much ingenuity was shown in these directions. The general practice was for the charging station to be erected at the most convenient point on the route and, if possible, close to the generating station, the latter obviously in order to reduce to a minimum the loss in transmitting the energy from the generator to the batteries. In some of the systems the appliances provided

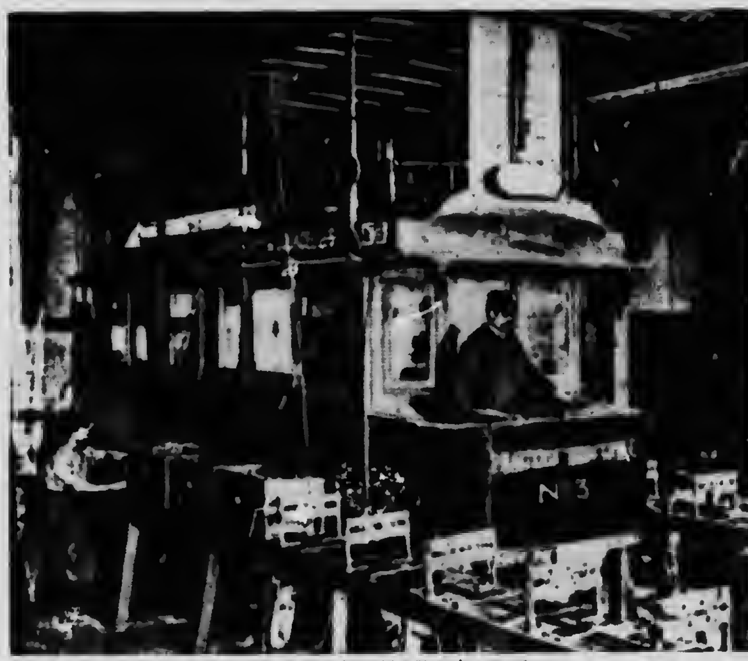


Fig. 1,589.—Car alongside Charging Platforms.

were so well designed that the average time for making a complete change of batteries was 90 seconds, and the change under favourable conditions has been made in the short period of 28 seconds, an excellent record when the weight of the batteries to be handled is regarded.

Much could be written regarding these systems and appliances, but for reasons already given we shall refer very briefly to one example only. The car carrying the nearly exhausted battery is run into the charging-room, in some cases to a particular spot where all changes are made, or to a special siding where there are unoccupied charging benches on either side of the track to receive the sections of the exhausted battery. In Fig.

1,589 the latter method is shown in operation. It will be noted that hinged covers at the side of the car have been raised, exposing the battery trays on the same level as the adjacent stands. The trays can therefore be easily slid on to the stands, on which there are sliding contacts which join them up in series for charging. When the exhausted battery has been removed the now "dead" car has to be hauled [illegible] by an electrically driven capstan or other device, alongside a bench on which there is waiting a charged battery which can be rapidly placed on board. The operation of pushing the battery trays home usually completes the necessary electrical connections.

Before leaving this subject, since the dead weight of the battery is one of the drawbacks of the system, the reader may be interested to know what proportion, in a typical instance, this dead weight bore to the other weights involved. In the case of a double truck tramcar in Paris, the figures were as follows:

Weight of car body	4·2	tons
Weight of trucks, motors, etc.	4·7	"
Weight of battery	3·7	"
Total weight of unloaded car	12·6	"
Weight of 58 passengers, driver, and conductor (say)	4·4	"
Total weight of fully-loaded car	17·0	"

The weight of the battery is thus seen to add 42 per cent. to the weight of the car and its electrical equipment, and to increase the weight of the fully loaded car by 28 per cent. Putting it otherwise, the weight of the battery is not far short of the full paying load of the car, and probably in excess of the average paying load.

VIII [illegible].—ELECTRIC VEHICLES AND AUTOMOBILES

One of the outstanding features of the changing aspects of road traction during recent years has been the diminution of the number of horse-drawn vehicles, and their replacement by motor-driven vehicles of varied types. This change has been due, to a great extent, to the rapid development of the use of petrol-driven vehicles and automobiles, but still more recently has been materially assisted by the almost equally rapid development of electrically driven vehicles and automobiles. As this latter development is still in progress it is not easy to select typical examples, but the following may be taken as a brief summary of the present position, illustrated by such details as are necessary to set forth the principles involved, and the chief methods of applying them in practice.

In Sections I., II., and III. of this Chapter we have dealt only with the conveying of the energy to the moving vehicle, and have postponed, to be dealt with in later chapters, the details of its utilisation and control on the vehicle. The same plan could be followed with regard to battery-driven road vehicles, but it would seem to be more convenient to treat the whole subject at once, and to deal here and now not only with the placing of the battery on the vehicle but with details of the utilisation, etc., of the electric energy. We propose, therefore, to deal with the electric vehicle as a whole, and in such detail as may seem desirable.

Fig. 1,590.—An Electric Automobile.

The usual course followed in such cases elsewhere in the book has been to give, in the first instance, a few typical examples of the complete machine, and then to deal with the details of electric and other equipment. If this course were followed in the present case it would be necessary to give

Fig. 1,591.—An Electric Omnibus.

illustrations of practically every type of road vehicle in existence, and this would serve no useful object. We give, therefore, just a few varied examples to illustrate chiefly the slight difference which the modification for battery working makes in the general appearance of a vehicle.

The Complete Vehicle.—The vehicles conveniently fall into the two

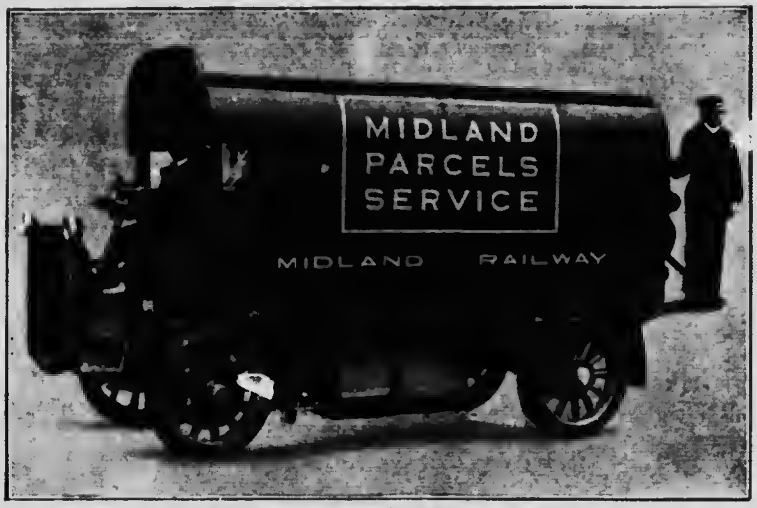


Fig. 1,592.—An Electric Parcels Delivery Van.

broad classes for passenger and goods service respectively. In the former there are all types, from the most luxurious pleasure vehicle to the strictly utilitarian "runabout," the hackney carriage, and the public omnibus. A convenient

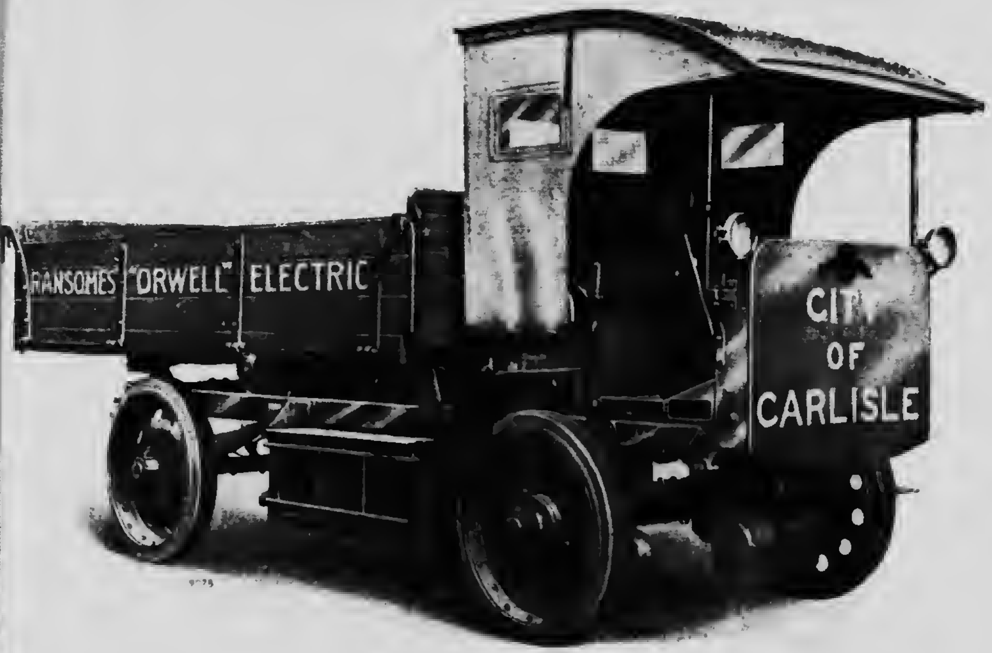


Fig. 1,593 An Electric Vehicle for Municipal Work.

form for pleasure or professional work is shown in Fig. 1,590, which, in exter- l appearance, can scarcely be distinguished from an ordinary petrol car.

Passing from private to public conveyances for passengers, there are, as might be expected, electric taxicabs and omnibuses. Of these we give an illustration in Fig. 1,591 of a group of three Edison omnibuses drawn up in the early morning at the terminus in Lancaster, and loaded with munition workers. The battery box can be seen between the steering and the rear wheels on the left-hand vehicle. Each omnibus is a single-deck vehicle, and carries twenty-two passengers, there being only one attendant, the driver, who also collects the fares.

Fig. 1,594.—A Battery-driven Electric Truck.

The number of commercial electric vehicles in use is now large, and it is difficult to make a selection. As a typical example of a standard type Fig. 1,592 is an illustration of a 30-cwt. parcels delivery van supplied to the Midland Railway Company, by Messrs. Ransomes, Sims and Jefferies, of Ipswich. The familiar bonnet of the petrol vehicle has disappeared, but the box underneath the van containing the secondary cells is

Fig. 1,595.—An Electric Truck in Use at Euston Station.

conspicuous. The method of charging these vehicles is illustrated in Fig. 1,618.

A heavier type of commercial vehicle, manufactured by the same firm for municipal purposes, is shown in Fig. 1,593. Here again the box containing the battery is conspicuous, and the electric driving motors, which will be described later, can also be seen. The body can be tipped by another electric motor, not visible in the figure, so that its contents can be discharged at the rear end.

A battery-driven vehicle is also specially adaptable for light work, such as the conveyance on trucks of goods in process of manufacture from one part of a factory to another, and for similar services in transport systems and elsewhere; in fact, electric trucks are now being used in large numbers for a great variety of work. An example of such a truck, as made by the Hunt Company, is given in Fig. 1,594; the battery, which is shown with the lid raised, is carried on the front of the truck over the driving wheels, which are ingeniously constructed motor wheels described later


Fig. 1,596.—A Standard "Orwell" Electric Chassis.

(see page 1477). The truck is 8 feet 10 inches long, and 3 feet 2 inches wide, can carry a load of 4,000 lb., and can be driven up to a speed of seven miles per hour. The power developed by the two motors is about 2 H.P.

Most of these trucks have a driver's platform, from which the truck can be steered and controlled. An Edison Elwell-Parker truck in actual use at Euston railway station is shown in Fig. 1,595. In this case the battery is carried below the load platform, which is left clear for goods, except for the controlling panel at the end. It should be noted that there is sufficient power for the truck to take charge of a trailer.

The Chassis.—Details of construction of the chassis or main framework, wheels, etc., upon which the body of the vehicle, the battery, and the driving and controlling machinery are mounted, scarcely fall within the scope of this book, but it will be of interest to our readers to understand the general plan of this important part of the complete vehicle. We therefore give in Fig. 1,596, a photographic view and in Figs. 1,597 and 1,598 line drawings of one of the standard "Orwell" electric chassis, constructed by Messrs. Ransomes, Sims and Jefferies. The type selected is one in which the driving motors M M are mounted on the steering wheels as described in detail on pages 1475 *et seq.* A plan, Fig. 1,597, and a side elevation, Fig. 1,598, are shown, in which details of the steering mechanism and of

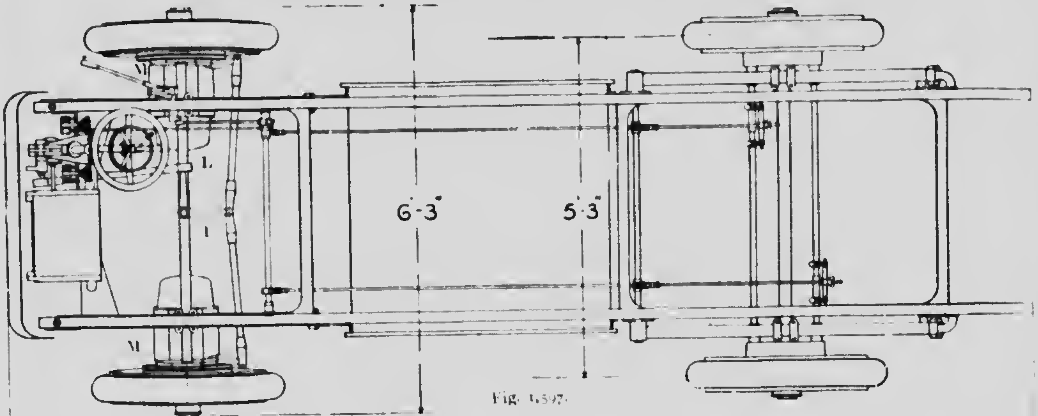


Fig. 1,597.

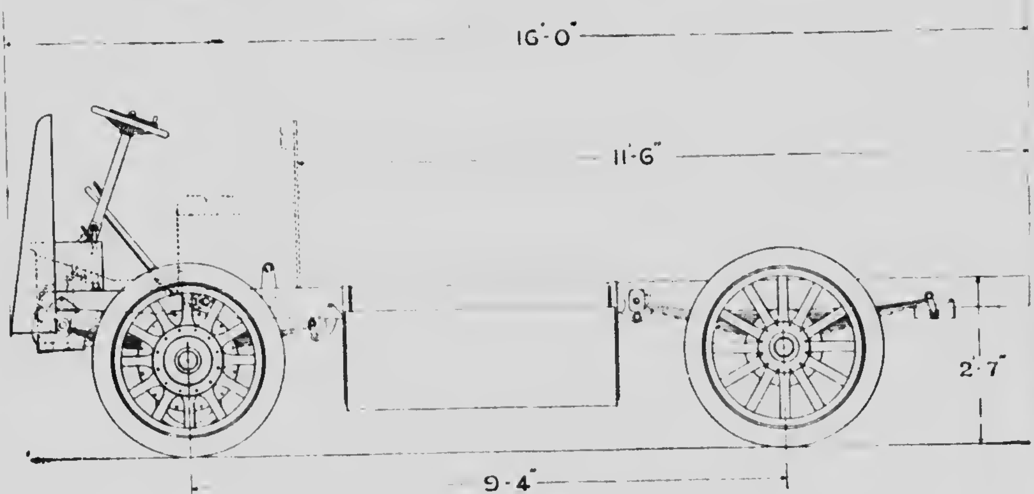


Fig. 1,598.
[Plan and Side Elevation of an "Orwell" Electric Chassis

the brake mechanism can be made out. The former is actuated from the steering wheel by a bell-crank lever L L, and in connection with it Plate XVII. should be consulted. Additional details of the steering wheel and the brake and control pedals are given in Fig. 1,599, which scarcely requires explanation. The brakes are on the hubs of the back wheels, and are controlled by both pedal and hand levers as shown; the pedal controls the service brake, and the hand-lever controls an emergency brake, both of these being of the internal expanding type.

One of the most interesting parts of the chassis, for our present purpose, is the arrangement for carrying the battery which supplies the energy. The battery is in two boxes, which are supported by means of angle irons R bolted to the sides near the top. These angle irons slide on light girders G G, carried by brackets under the main framework of the chassis; and by a special arrangement, which is shown in greater detail on Figs. 1,600 and 1,601, each box can be slid outwards for examination without removing it from the chassis. Fig. 1,600 shows the battery in the running position, and Fig. 1,601 shows it pulled out and with the lid of the containing box removed.

Fig. 1,599.—Steering Wheel and Brake and Control Pedals of an "Orwell" Electric Vehicle.

The chassis illustrated in Figs. 1,596 to 1,598 is to carry a load of 2.5 tons, and itself weighs approximately 35 cwt., the additional weight of the battery being 22 cwt. The speed attainable on the level is twelve miles per hour, and the lead battery of 40 cells will run the vehicle 30 to 40 miles without recharging.

Fig. 1,600.—The Electric Battery in the Running Position.

Fig. 1,601.—The Electric Battery Drawn Out for Inspection.

Details of the motor and the electrical control are given elsewhere (*see* pages 1476 and 1480).

A standard Edison-Lansden chassis is shown in plan in Fig. 1,602. In this case the rear wheels are driven by a single motor which is mounted with its axle fore and aft between these wheels. This motor drives the counter shafts by bevel-gear, thus giving a first step-down in the angular speed, which is still further reduced by the sprockets at the ends, each driving one of the rear wheels by a roller chain. The battery is in two parts, carried underneath the main frame on roller-supported trays which can be pulled out sideways. The standard power equipment is 60-Edison A-8 cells (*see* page 1069) giving about 300 ampere-hours at 60 to 70 volts.

As a final example a chassis is shown in Fig. 1,603 with a single motor driving the back wheels by means of a propeller shaft, in much the same way that the propeller shaft from the gear box of a petrol engine can be coupled up to drive the back wheels of a petrol automobile. This

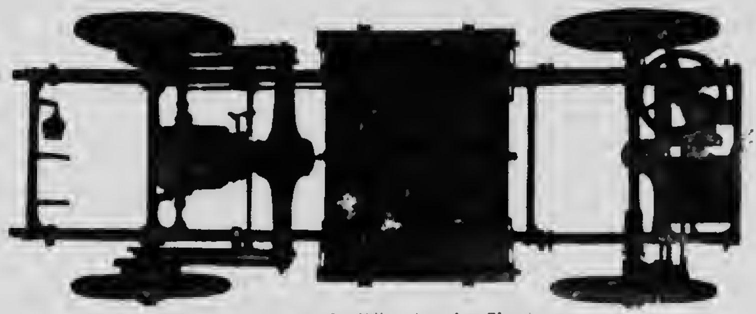
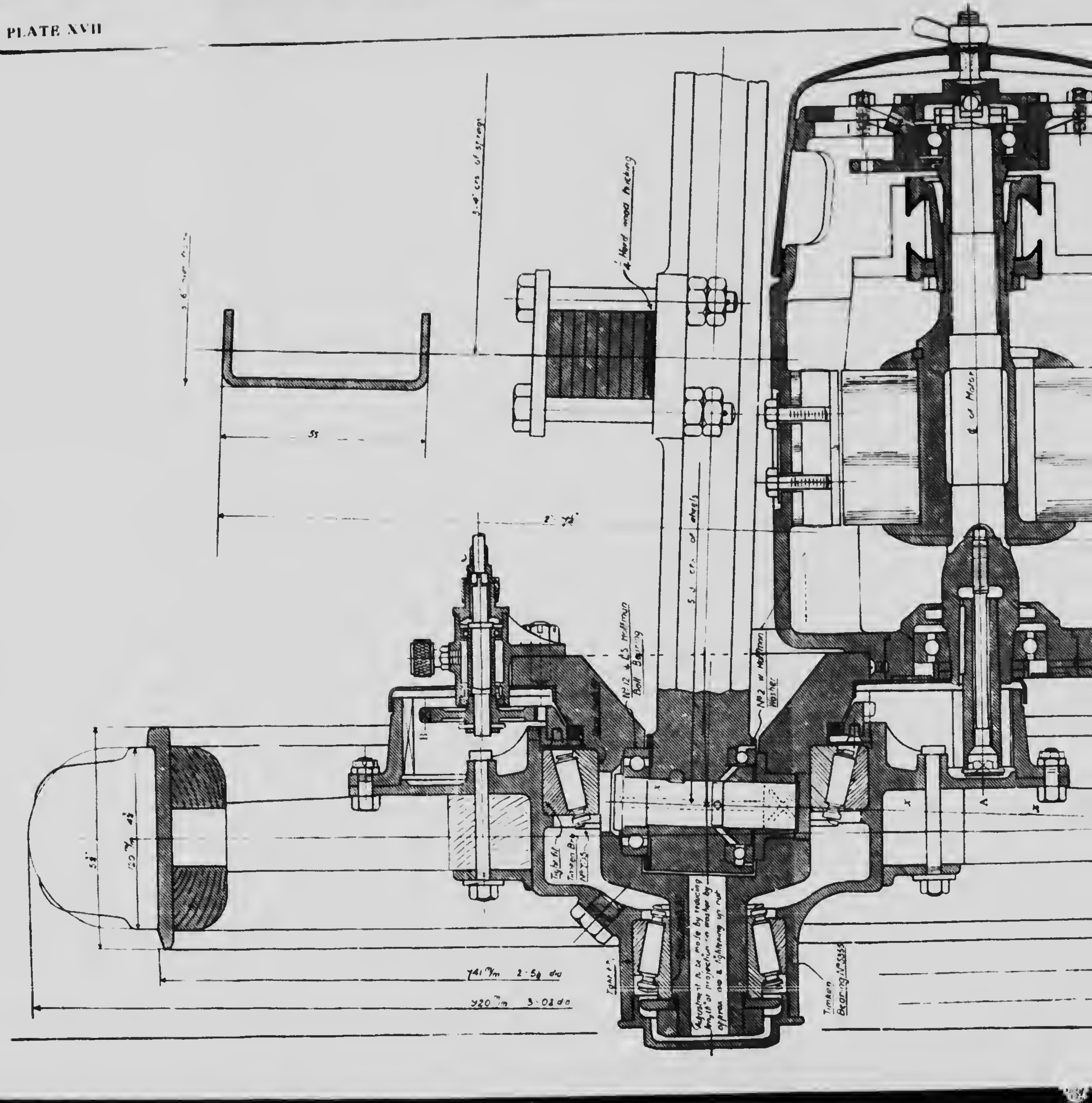


Fig. 1,602. An Edison-Lansden Chassis.

chassis is manufactured by Messrs. W. A. Stevens, Limited, whose petrol-electric vehicles are referred to later. The motor M, which is well designed according to good modern practice, and is mounted longitudinally on the chassis, can be clearly seen in the figure, with its armature shaft projecting backwards to the rear axle, the enlarged central portion of which contains the worm gear and differential bevel wheels by which the power is transmitted and the necessary speed reduction made. The chassis weighs $2\frac{3}{4}$ tons without the battery, and is designed to be fitted with a 3- to 4-ton lorry body. The gross weight of the vehicle, which is driven by a lead battery of 80 Tudor cells, is 7 tons loaded, and the average speed on the level is 12 miles per hour.

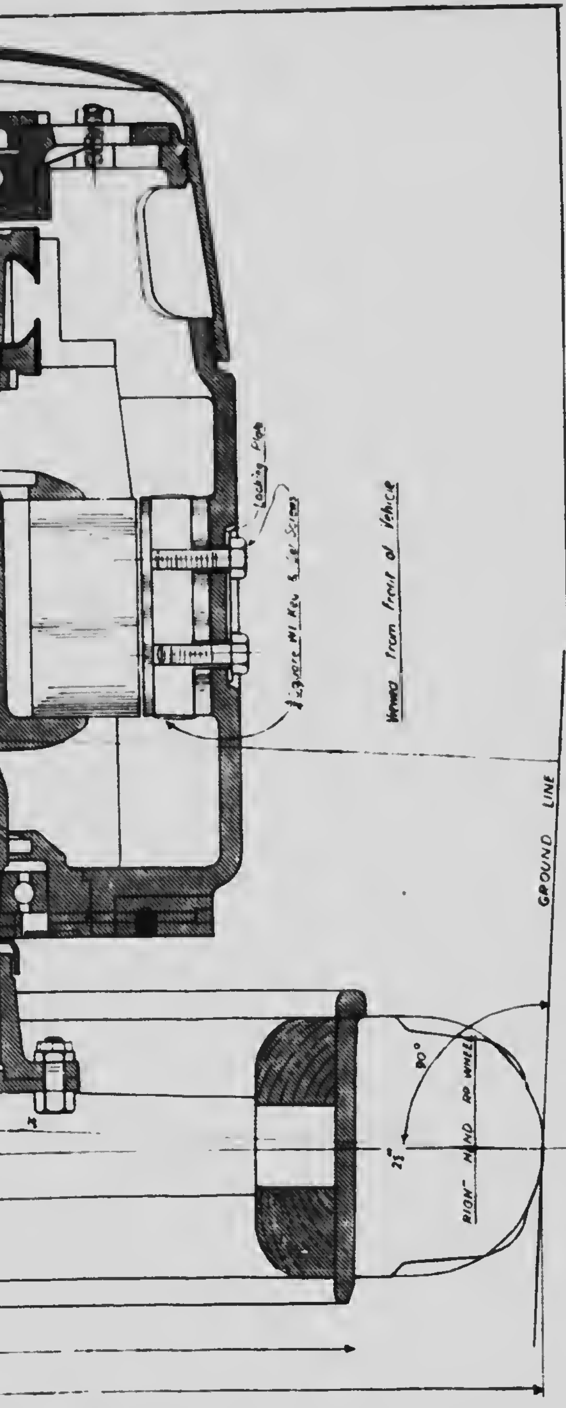
The Motors.—The electric features of a secondary cell are its low voltage and relatively high ampeage, but one of the conditions in its use on an electric vehicle is that it is so close to the motor that losses in the leads in transmitting the power from the cells to the motor, though not negligible, are so small that the electric power may be economically supplied at a

PLATE XVII



Hard wood packing
Motor
Nº12 & C.S. Hoffmann Ball Bearing
Nº2 W Hoffmann Washer
Timken Bearing
Adjustment to be made by reducing length of projection on washer by approx. and tightening up nut
741 m/m 2·5 dia
920 m/m 3·02 dia

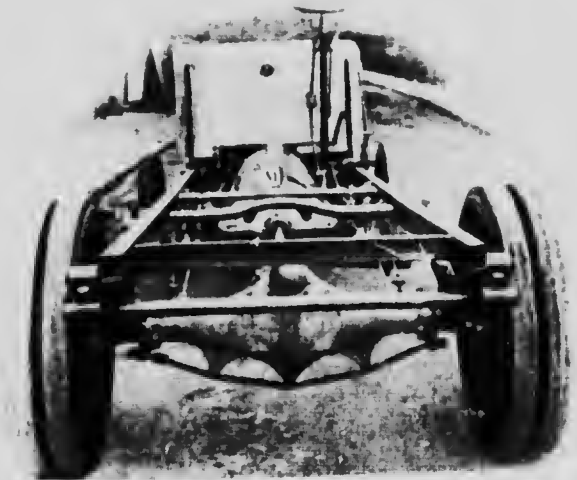
To face page 1475



ONE OF THE DRIVING MOTORS OF A 2½-TON "ORWELL" ELECTRIC VEHICLE.

lower voltage than is usual in other applications. For instance the A 12 Edison Cell on a seven hours' discharge gives about [illegible] amperes or [illegible] watts. If a battery of such cells is required to furnish two kilowatts it must contain not fewer than 24 cells, the discharge rate of which will be about 29 or 30 volts; a three kilowatt battery would contain 3[illegible] cells with a rate of about 42 volts. In lead batteries the voltage per cell is higher, and therefore a smaller number of cells may be used with the same amperage and final voltage, or a lighter cell of lower amperage but requiring more to give the necessary power. Thus an 80-watt lead cell will have a seven hour discharge current of about 44 amperes at 1.96 volts; 35 of these would still be required to give 3 kilowatts, but the voltage would be 68 volts.

The appropriate electric motors are therefore somewhat low-voltage motors taking for their size comparatively large currents. For the purpose of running economically at different speeds, as explained in the chapter on controllers, and for other reasons, it is desirable, though not necessary, that two motors should be used on each vehicle. If two motors be used they may be mounted as in Fig. [illegible], to drive the front or steering wheels directly through a pinion and crown wheel, or they may be mounted beneath the body so that each drives one of the rear wheels by means of a chain and other suitable speed-reducing drive. Where one motor is used it may (as in Fig. [illegible]) drive the rear wheels through suitable gearing, much in the same way that the engine drives the rear wheels of a petrol vehicle, or it may be mounted, as we shall see presently, directly on the shaft of the rear wheel.



[illegible] Stevens [illegible]

The most interesting case is probably that first mentioned, and we therefore give in Plate XVII a scale drawing with some of the principal dimensions marked, of a vertical section through the axle of a motor mounted to drive directly the right hand wheel of a 2½-ton electric lorry similar to that shown in Fig. 1,593. The drawing is taken from an "Orwell" electric vehicle, manufactured by Messrs. Ransomes, Sims and Jefferies. The motor is bolted to the swivel axle of the vehicle, and is of the totally enclosed type provided with brass end shields, the cover being watertight. One of the front wheels of a 2-ton vehicle is shown in Fig. 1,604, without the axles and motor, but with the crown wheel and its helically cut teeth, and the smaller gear wheel can also be seen. The helically cut pinion on the end A of the motor shaft and the helically cut spur gearing into which it meshes are still more clearly depicted on a larger scale in Fig. 1,605. Referring to the plate, it will be seen at A that a pinion on the axle of the motor gears into and drives the crown wheel; the speed reduction is 12½ to 1. In its turn the open gear on the wheel is seen at B to drive the axle C with an increase of speed of 1 to 4, so that the shaft C revolves at about one-third of the speed of the motor armature. The gears work in a dustproof and waterproof casing filled with grease, giving excellent lubrication which requires very little attention. Shaft C drives a combined speedometer and mile-meter by means of a flexible cable running in a flexible tube.

Fig. 1,604.—Driving Wheel of a 2-ton Electric Vehicle.

The details of the motor, which is a four-pole machine, will be understood from the descriptions of somewhat similar motors in Chapter IV. At top speed it runs at 3,000 revolutions per minute, and has both shunt and series excitation, the latter being the main excitation, and the other used for speed control. The normal full load of the motor is 2¾ B.H.P., at which it takes 30 amperes at 80 volts. The maximum speed at full load on the level is 1,350 R.P.M., but the maximum output of about 7 B.H.P. is obtained at between 500 and 600 R.P.M., and at this heavy

Fig. 1,605.—Helically-cut Transmission Gear.

overload the efficiency is still as high as 78 per cent. It should be noted that the wheel, the motor shaft, and the shaft c are all supported by ball bearings, and that as the wheel is a steering wheel special bearings are used to give it the necessary freedom of motion, the axle, x x, round which swivelling occurs, passes through the tread of the wheel on the ground, thus avoiding the transmission of shocks to the steering wheel, which is, in consequence, easy to manipulate.

A still more ingenious method of mounting the motor on the wheel, which is possible when the power required is not large, is to place the motor inside the wheel itself as shown in Fig. 1,606. The motor, which can develop about one horse-power at 1,000 R.P.M., is securely mounted by a stub axle on the steering pivot or axle. It is a two-pole motor, and, as

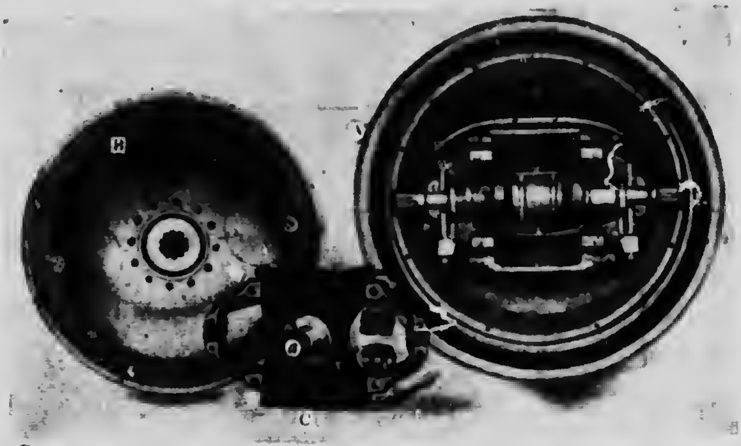


Fig. 1,606.—An Electric Motor Wheel.

shown at A, drives by means of bevel pinions on the end of its shaft the revolving housing on which the rubber tyre is mounted. The front part of the magnetic circuit with brush gear and half bearings has been removed, and is shown at C; it carries the stub axle *a*, on which the cover B with its crown wheel revolves. The shaft of the motor is set somewhat out of centre vertically so that the right-hand pinion engages with the crown wheel in A. The left-hand pinion clears that crown wheel, but engages with the crown wheel in the cover B when all the parts are assembled, and B is slipped on to the stub axle and secured. Both ends of the shaft therefore drive the housing, giving a balanced gear with a steady turning effort or torque having a minimum of friction and wear. The gear ratio is about 12 to 1. One of these wheels is shown in use on the truck illustrated in Fig. 1,594.

One method of driving where only a single motor is used has been described and illustrated in Fig. 1,602 (*see* page 1474). Another method designed by the same firm, Edison Accumulators, Limited, is shown in Figs. 1,607 and 1,608. In this case the motor is mounted within the rear axle, which is expanded into a hollow torpedo-shaped body. This body is divided horizontally into two parts which are bolted together, and is shown opened up in Fig. 1,607, exposing the contained motor which is seen to be a four-pole motor very similar in many respects to the traction motors described in Chapter IV. (*see* pages 622 *et seq.*). Two of the poles and the brush gear are carried by the upper part of the casing, which is hinged to the lower part containing the rest of the motor. The armature shaft is hollow, and is directly connected to the differential gear seen at D, from the differential sockets of which the two driving shafts extend, each one into the centre of one of the rear wheels, the wheel end of the shaft terminating in a pinion. This pinion, as shown in Fig. 1,608, gears into two idle gear wheels which are mounted on the axle yokes, and which drive the tyre-carrying housing by means of a crown-wheel gear; the drive is a balanced one, being applied simultaneously at two ends of a diameter of the crown wheel.

Fig. 1,607.—Edison Shaft Motor.

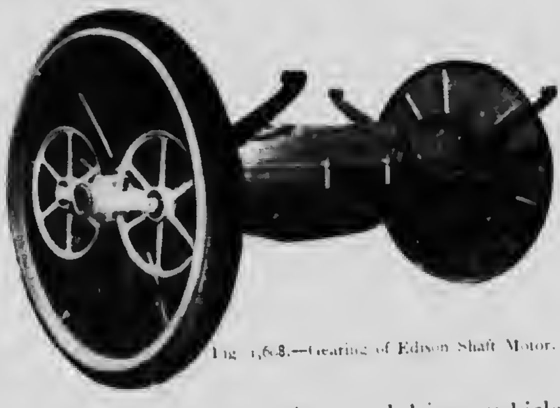


Fig. 1,608.—Gearing of Edison Shaft Motor.

The Speed Control.—One of the great advantages of the electric vehicle as compared with the petrol-driven vehicle is the simplicity and ease of the control of the speed. The gear box, which is mechanically bad, is abolished, and its place taken by resistances and circuit connections which can be operated to meet the circumstances of the moment by sliding contacts or switches of simple pattern and easily manipulated. Any necessary speed can be obtained, from dead slow to top speed, though for running purposes the details are so arranged that certain speeds are more economical than others. There is no "cranking up" for a start such as is sometimes so troublesome with a petrol engine.

Where one motor only is employed it is series wound, thus obtaining the advantages, described elsewhere, of this type of motor for traction service. One method of obtaining the necessary control is to lower the available voltage for starting purposes and low speeds by putting the two halves of the battery in parallel, giving half voltage, and connecting a regulating resistance in series with the motor. For the next speed the regulating resistance is removed. For the third speed the two halves of the battery are put in series, giving full voltage, and the regulating re-

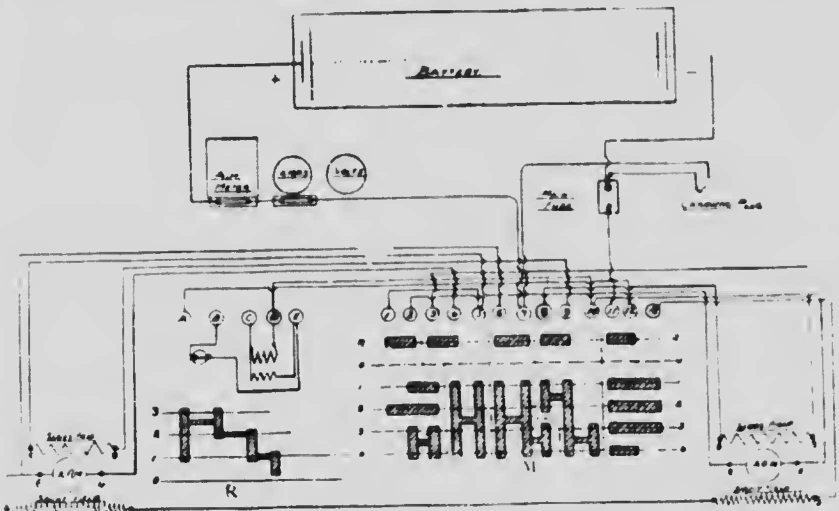


Fig. 1,660.—Details of the Lay out and Connections of Main and Auxiliary Controllers for Two Motors.

sistance is reintroduced into the motor circuit; whilst for the fourth or top speed this resistance is short-circuited. Reversal can be obtained by a separate reversing controller, which, in principle, is the same as that depicted in Fig. 655, and which can only be operated when the main controller is in the "off" position. A pedal switch supplies a convenient method of introducing or short-circuiting the regulating resistance, and thus altering the speed up or down.

Where two motors are employed the method adopted is that of the series-parallel control, which is fully described elsewhere (*see* page 1633). The motors are series wound, but sometimes a shunt winding is added for regulating purposes. This method of control renders it unnecessary to parallel the two halves of the battery, which has the disadvantage that if the voltages of these two halves differ slightly there will be a current circulating in the battery which is very undesirable. The multiple switch employed in any of these methods is usually known as a *controller*, and a diagram of the connections for a series-parallel controller, as adopted by Messrs. Ransomes, Sims and Jefferies, is given in Fig. 1,609. There is a main controller M on the axle of the steering wheel with one off and four forward running positions, and one backward or reverse running position. In addition there is a resistance controller operated by a pedal, the connections of which are shown at R, in which the line marked "3" is the position of rest. In this position all the resistance is in series with the circuits established by the main controller. When the pedal is depressed it takes up successively the positions "2" "1" and "0," in the first two of which the two resistances are short-circuited one after the other, thus increasing the voltage on the motors, but when pushed home to position "0" the circuit is completely broken, and the power removed, a very useful result in a sudden emergency; but what is

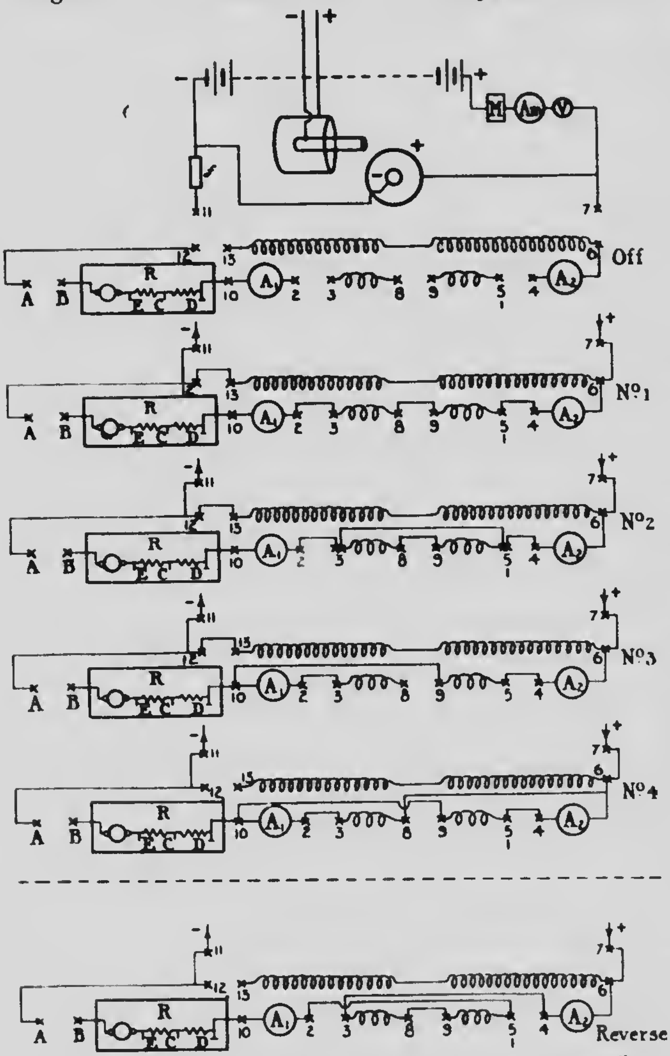


Fig. 1,610. Diagrams of the Circuits of the "Orwell" Two-motor Controller.

usually of more importance is that it enables the main controller to be moved from one position to the next with the circuits open, and therefore without sparking.

Sketch diagrams of the circuits for each position of the main controller are given in Fig. 1,610, the pedal resistance controller just referred to being placed in the gap A-B, which is normally closed by it. These diagrams will make clear the operations of both controllers. In the position marked "off" all the gaps are open except A-B, which, however, is shown open in all the diagrams, as this is the "change-over" position for the other controller. In position "No. 1," the starting position, of the main controller, it will be found that the two motors and their series fields are all in series; in "No. 2" the armatures are in series but the series field coils are short-circuited; whilst in "No. 3" only one motor is in circuit, and gets the full voltage in its series field coil and armature. In each of these three positions the shunt field coils are excited with the full voltage of the battery. In position "No. 4," the full power and maximum speed position, the shunt circuit is broken at the gap 12-13, and the two motors are in full parallel.

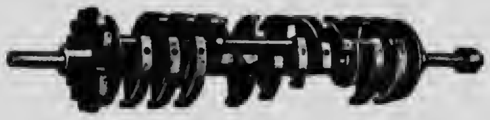


Fig. 1,611.—Controller Cylinder for an Electric Vehicle.

A reference to Fig. 1,609 will show that the "reverse" position can only be reached by passing back from No. 4 through 3, 2, and 1, to the "off" position. The diagram "Reverse" in Fig. 1,610 shows that the two motors are in series with the current flowing in the reverse direction through their series fields, and with the shunt fields broken.

The reasons for these various changes, which give progressively increasing speeds, and the principles underlying them have been fully explained in the chapter on the "Continuous-current Motor," and need not be repeated here.

The *Controller* usually is of the cylinder type described in the chapter on continuous-current motors (*see* page 645), and more fully referred to later on pages 1633 to 1646. The rotating cylinder with its contact segments of appropriate lengths may either be arranged to rotate round the axis of the steering column, or may be placed in a box so that it can be rotated by a hand lever or a pedal within reach of the driver. The main cylindric drum for the controller described above is shown in Fig. 1,611; it is operated by a gate change lever mounted on the side of the driver's seat.

A complete controller arranged for a somewhat different sequence of operations is shown in Fig. 1,612. It is of a pattern designed and manufactured by the Igranic Electric Co., and is intended to be placed under the driver's seat for left-hand operation, the front of the controller being at the right-hand side in the figure. There are an "off" and five working positions of the lever, designed to control a single series motor or two such motors permanently in series and with no shunt excitation. In the former case the field winding is in two parts for series or parallel connection. In positions 1 and 2 the motor field coils are in series, and there are resistances on the circuit; in positions 3, 4, and 5 there are no resistances in the circuit, but in 4 the fields are in parallel, and in 5 they are also shunted, and therefore weakened for the top speed. Magnetic blow-outs are provided where necessary. The two resistances of the cast-iron grid type used in the motor circuit are shown outside the box containing the controller drum and fingers. Behind the operating lever L there is mounted a safety switch worked by the rod S. Pulling up this rod cuts off the current, whatever be the position of L, but the mechanisms are so interlocked that S when pulled up cannot be depressed to restore the current until L has been brought to the "off" position. S thus acts as a main switch. Such a main switch can be also interconnected with the foot-operated brake so that it is always moved to the open circuit position when the brake is applied. This prevents the brakes being applied when the power is on and working against that power, a state of things

Fig. 1,612.—"Igranic" Controller for a Motor Vehicle.

which may lead to the burning out of the motors because of their inadequate back E.M.F.

The controller shown in Fig. 1,612 has also three positions, in the further slot, for reverse running, these corresponding to positions 1, 2, and 3 for forward running. It is, however, often more convenient to have a separate reversing switch operated by a pedal, but only movable when the lever L is in the "off" position.

Similarly constructed controllers are available for the double-voltage method of control described on page 1479 as being used when only a single motor is employed.

Arrangements for Recharging.—The commercial success of a battery-driven electric vehicle will obviously be dependent on the efficiency and convenience of the arrangements for recharging the battery when exhausted or nearly exhausted, as well as upon the number of miles the vehicle can run on a single charge, and the manner in which this mileage meets the requirements of the work which the vehicle is ordinarily called upon to do.

The efficiency of the recharging arrangements as a whole depend upon (i.) the provision and (ii.) the equipment of a conveniently distributed number of recharging stations and sub-stations.

With regard to (i.), electric transmission and distribution mains are now so numerous in many parts of the United Kingdom that one ventures to hope that a public supply of electric energy for such vehicles may, in the not distant future, be "on tap" in so many places as to reduce materially the loss and inconvenience of having either to recharge before the battery voltage has fallen sufficiently or to run the risk of being stranded far from home with an exhausted battery on board. To meet some of these difficulties, a system of giving short charges, known as "boosting" charges, to unexhausted batteries has been employed, and will be referred to again later.

The equipment of a charging station or garage follows generally the lines of the equipment of the continuous-current sub-stations already described, the chief modifications being (i.) that the output voltage is lower than is usual for ordinary power or lighting purposes, and (ii.) that arrangements should be available for supplying the required power economically at the particular voltage suitable for any electric vehicle which may apply.

A sub-station especially designed for the recharging of automobile secondary batteries has already been illustrated in Fig. 1,111 and described at page 1085. In this case *mercury-arc rectifiers* were used as transformers to reduce the ordinary supply voltage, and appear to be well adapted for this particular work. With what has already been said in other parts of this book on the subject of continuous-current sub-station working, one or two additional illustrations of special stations for electric vehicles will suffice here.

The main object is to obtain a supply of continuous-current energy at a range of voltages suitable for the particular battery, having regard to the well-known charging curves already given elsewhere. If the main supply be A.C. any of the relevant methods described in Chapters VIII. and X. can be used. Simplicity of control and working are, however, desirable, and probably for the kinetic transformers an A.C. motor coupled to a C.C. dynamo on the same bed-plate is the simplest. The mercury-arc rectifier is available as just pointed out.

With a C.C. supply on the mains the question is reduced to one of voltage regulation. The usual voltages of public supply for power purposes in England are 500, 440 and 220, all of which are too high for ordinary battery vehicles, the voltage for which lies somewhere about 80 volts. To reduce by dead resistance is obviously wasteful, as, for low voltages, more energy would be used up in the resistance than in charging the battery. In fact, the efficiency might fall as low as 16 to 17 per cent. on 500-volt mains. A coupled C.C. motor and dynamo, with quite distinct electrical circuits, would be more economical, and could be worked at an overall efficiency of 75 per cent. A still more economical plan is to place the armatures of the motor and dynamo of a coupled plant in series as shown diagrammatically in Fig. 1,613, which gives the connections of a "reduced" set manufactured by the Lancashire Dynamo and Motor Company. Both machines have shunt excitation, the shunt circuits being in parallel across the mains, and the shunt circuit of the dynamo having a regulating resistance to adjust the voltage across the terminals of the battery to be charged. The starting and the automatic safety devices are in the usual positions, which have been explained in Chapter IV. One of these sets is shown in Fig. 1,614, together with a switchboard panel containing the necessary

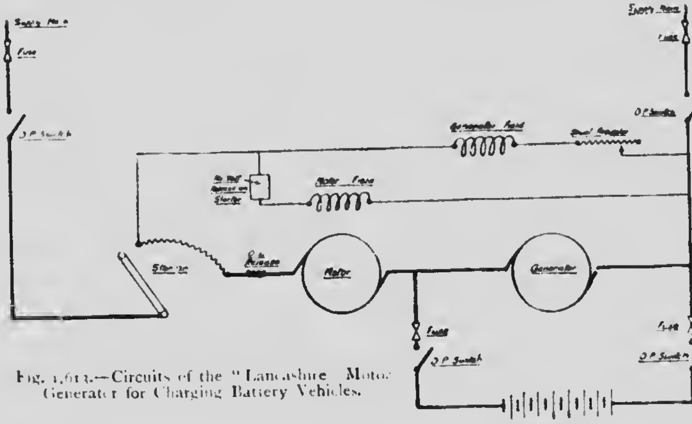


Fig. 1,613.—Circuits of the "Lancashire" Motor Generator for Charging Battery Vehicles.

controlling apparatus and measuring instruments. The overall efficiency of the set varies with the voltages of the supply circuit and the battery, but under ordinary conditions is not less than 80 per cent., and may be as high as 87 per cent. This efficiency must not, of course, be confused with the efficiency of the battery, which is quite another thing.

If two or more batteries which do not differ widely in voltage are to be charged at the same time, the batteries may be paralleled on the dynamo or the mains, and it will be necessary to provide rheostatic regulation for each

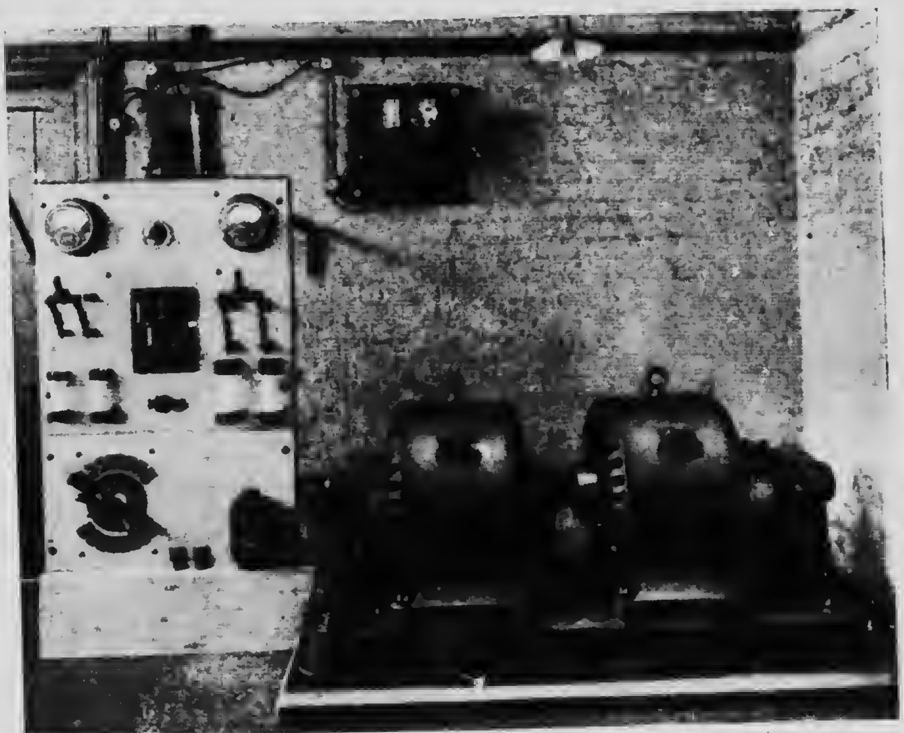


Fig. 1,614 The "Lancashire" Motor Generator Set for Charging Battery Vehicles.

battery separ[illegible] A panel constructed by the Igranic Electric Co. to provide for a [illegible]um of three batteries being simultaneously charged is shown in Fig. 1,615, though apparatus for only two batteries appears on the figure. The upper part of the panel contains the switches, fuses, regulators, etc., for a motor-generator set and the measuring instruments for use as explained below. The charging units are the two horizontal sections on the lower part of the panel, and it will be noticed that there is room lower down for a third. One of these sections is shown separately, on a larger scale, in Fig. 1,616. It measures 24 ins. by 10 ins., and is a complete unit in itself, inasmuch as it carries on the back the necessary regulating resistance, the sections of which are brought to the sliding contacts shown on the front. This adjustable resistance is interposed between the main battery switch and the battery, in series with the latter. In addition to the resistance contacts and the sliding brush the front of the section carries at the left-hand side a low-current circuit-breaker C, which also acts as a battery switch, and on the right-hand side a three-position instrument switch S; there are also the necessary fuses, a pilot lamp, and a card-holder to indicate the circuit controlled. The circuit-breaker is interlocked with the sliding brush, so that it cannot be closed unless the latter is in the extreme left-hand position in which all resistance is in circuit. When closed C is held in position by a small magnet, but is released if either (i.) the charging voltage falls below the battery voltage, or (ii.) the service fuses "blow."

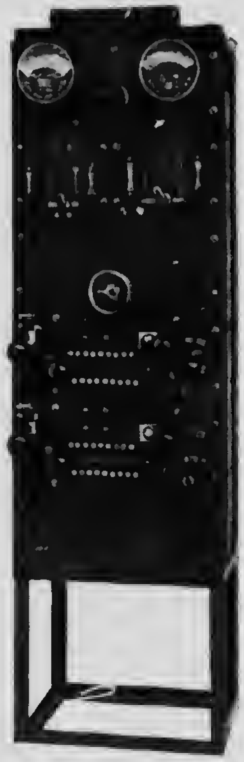


Fig. 1,615.—"Igranic" Panel for Charging Electric Vehicles.

With all switches open, if a battery be connected to the charging circuit of the section the pilot lamp will glow because it is electrically across the battery terminals. If the switch S be now moved to the "reading" position, it will show on the voltmeter on the panel the voltage of the battery, and also, by the direction of the deflection, whether the battery poles are on the proper leads. If all be right and the sliding contact brought to the extreme left of its range, the circuit-breaker C can be closed and the battery placed on charge, the slider being then moved to the right until the charging current, as shown on the ammeter, rises to the desired value. The switch S is then to be released, and will be forced by a spring into its "closed" position, in which the instruments are disconnected but the battery left on charge. The voltage and current on the battery on any section of the panel can be ascertained at any time by moving the switch S of the section to the "reading" position. When the charging is to be discontinued the switch S is moved to its third or "open" position, the arc formed on opening the circuit being taken

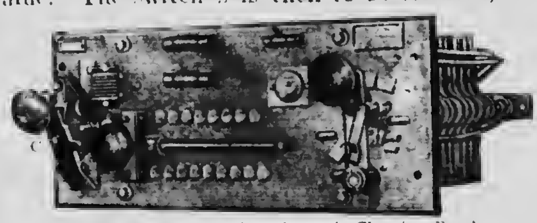


Fig. 1,616.—Single Section of Igranic Charging Panel.

on auxiliary contacts provided with a magnetic blow-out. As soon as the circuit is thus broken the circuit-breaker C opens and disconnects the battery from both sides of the "line," and by the subsequent removal of the charging plug from the vehicle the charging cable becomes entirely "dead."

Where numerous vehicles are to be charged simultaneously, the arrangements for maintaining a supply of current at a standard voltage are those of an ordinary C.C. sub-station as described in Chapter VIII., and the arrangements for paralleling the batteries on the mains can be made quite distinct. The Igranic unit just described has been designed so as to be available for this case, and a built-up switchboard with 20 such units is shown in Fig. 1,617. No further description is necessary, except to point out that the combined ammeter and voltmeter, which can, when required, be used for any one of the twenty sections, is on a swinging bracket at the side and can be read from any position. All the line and battery connections are on the back, and the installation of the switchboard is a comparatively simple matter.

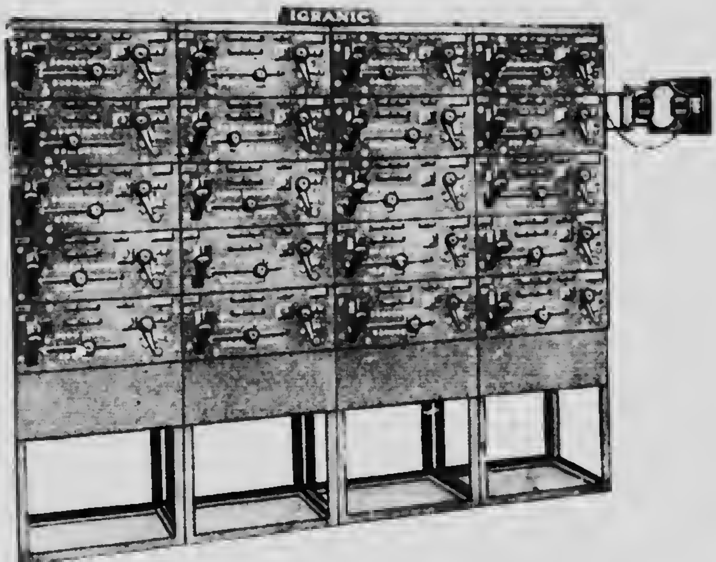


Fig. 1,617.—Panels for Simultaneously Charging Twenty Electric Vehicles.

To illustrate the other end of the charging process, Fig. 1,618 shows the charging of electric vehicles at the Midland Railway Company's depot at St. Pancras, London. All that is necessary is a plug and a flexible connection to a fitting sunk in the ground, the energy taken being recorded on a supply meter on the vehicle.

Public electric supply undertakings, municipal and other, are increasingly recognising the advantages of catering for the supply of electric energy for battery vehicles, as a means not only of increasing their output, but, if properly handled, of improving their own power factor.

Fig. 1,618.—Midland Railway's Charging Station for Electric Vehicles.

In a return published in 1917 by the Electric Vehicle Committee, about 170 public charging stations were scheduled as being available in Great Britain, of which 39 were in London itself or within the twenty-five mile circle from Charing Cross.

An electric vehicle garage in connection with the municipal electricity works in Ipswich is shown on Fig. 1,619. Here connection is made to the vehicle to be charged by a flexible cable which terminates at a wall fitting. The switchboard and controlling apparatus can be seen at one corner of the garage.

Even more convenient under certain circumstances is the arrangement shown in Fig. 1,620, made by the Croydon Corporation, by which passing vehicles drawn up to the kerb on the road outside the generating station can be rapidly connected to a heavy charg-

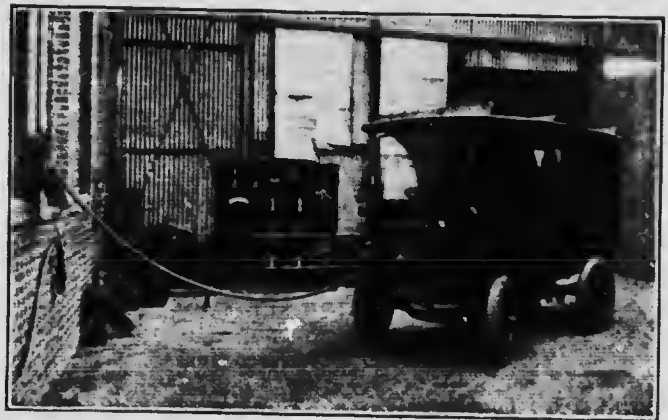


Fig. 1,619.—Municipal Charging Station at Ipswich.

ing flexible and be given either a brief "boost" or a longer and fuller charge. The flexible cable is brought out from the station on a swinging bracket, which, when not in use, can be folded back against the wall with the heavy cable drawn up out of harm's way by the suspending rope shown in the picture. Permanent connections inside the station can, of course, be made alive at a moment's notice, and the supply of "juice," as it is colloquially called, turned on as if it were water from a tank supplied through a hose pipe.

As a final illustration in this direction, we give in Figs. 1,621 and 1,622 two views of a kerb-side charging station which consists of a weatherproof box supported on a more or less ornamental pedestal. The box contains, mounted on a slate panel, a regulating rheostat, switches, fuses, ammeter polarity indicator, etc. Connection with the c.c. supply is made through a conduit passing under the side walk. A prepayment meter can be installed, but in view of the numerous sizes and types of batteries which may require a supply of energy, a technically trained attendant should usually be available.

Fig. 1,620.—Electric Charging at Croydon Electricity Works.

In this connection it may be well to note that the Electric Vehicle Committee has adopted a "standard charging plug and receptacle," which is now widely installed on vehicles and in charging stations, so that the electrical connection for charging can be made without delay. The fittings are designed to take currents up to 150 amperes, and serve for the midday "boost" as well as for the regular charging.

"Boosting" Charges. The midday "boost" referred to in the last paragraph and also earlier in the section is a modern development

rendered possible by the multiplication of charging facilities, and having an important effect on the economical working of motor vehicles, especially for commercial purposes. A "boosting" charge is a partial charge given in a comparatively short time by means of currents higher than the normal charging current of the particular battery. Circumstances often arise in ordinary working under which the normal charge may not be sufficient for the round trip. Thus, after a snow-storm, the roads may be heavy and require abnormal power to propel the vehicle, or under ordinary conditions a trip longer than the usual may become necessary. If then, when the battery has been partially discharged and the vehicle is for other reasons at a standstill, e.g. during the dinner-hour, the necessary facilities are at hand, the battery can be "refreshed" by a partial recharge at as high a rate as it can stand. The rate must not be so high as to injure the battery permanently, but provided gassing and over-heating do not appear, the plates are probably absorbing usefully the energy supplied.

Fig. 1,621. Fig. 1,622.
A Kerb-side Charging Pillar for Battery Vehicles.

It has been found that a one-hour boost properly applied to a lead battery which has been half-discharged increases its capacity 32 per cent., and if it be fully discharged the increase of capacity is 50 per cent. The precautions necessary have been indicated in the chapter on secondary batteries; space does not permit us to repeat them in detail here.

Position and Prospects of Electric Vehicles.—As remarked above, it is only within recent years that electric vehicles have given signs of coming into their own, and have established their position as distinctly commercial propositions, whether used for the carriage of goods, for public conveyance, or for pleasure purposes. In the early days they were handicapped by defects in the secondary batteries, which have been much improved for their purposes since the beginning of the present century, but more still by financial difficulties and bad management, quite independently of the engineering position. In addition to the improvements in batteries, electric motors have been improved and developed for this particular service, and by the use of ball-bearings and careful attention to minor points in design, their contribution to the increase of overall efficiency has been quite appreciable.

In the two or three years before the outbreak of war much good work was done, and there emerged a prospect of rapid and profitable development, which has, however, been retarded by the difficulties incidental to war conditions. Steady progress has, however, been made, and the Electric Vehicle Committee was able to report that on March 31st, 1917, there were 914 electric industrial vehicles in use or on order, as against 680 a year earlier, an increase of about 35 per cent. But these figures are much too small in view of the possibilities now in sight, for it has been estimated that in a certain area on the outskirts of London 1,200 electric vehicles would not be excessive for the traffic requirements, and that this number would require practically as much electric energy as is supplied to the local tramcars. The importance of such a development from another point of view becomes obvious when it is further observed that this energy could be supplied by the local generating station by an improvement of its load-factor, without increasing the maximum demand on the plant. The improvement of the load-factor would lead to the cheapening of the production of electric energy for all purposes. When it is stated that as far back as 1913 there were over 2,100 electric industrial vehicles in 70 lines of business on service in New York alone, it will be realised that there is a large field for development in this country.

Performance.—In considering the performance of electric vehicles one's attention is more directed to the over-all cost of running and maintenance than to the engineering efficiency of the whole machine. The efficiency of electric motors as motors only is well known, and the efficiency of lead secondary batteries, in this connection, may be taken to be about 75 per cent. The intermittent nature of the services demanded, however, profoundly affects the final cost, the reduction of which to a minimum is usually the aim of the engineer. It is from this point of view, therefore, that the problem is approached.

The curves given on Fig. 1,623, for which the writer is indebted to Mr. A. J. Makower, exhibit graphically the results obtained as affected by the nature of the services demanded. The abscissæ are the number of miles per annum run by an electric commercial vehicle of the "Orwell" type, which is fully described in the preceding pages (*see* pages 1470, *et seq*). The range taken is from 3,500 miles per annum, which is only 67 miles per week, or about 12 miles per working day, to rather more than three times these distances. It may here be explained that experience shows that in London the ordinary conditions of distribution lead to a possible average of about 32 miles per day, and that in other large cities

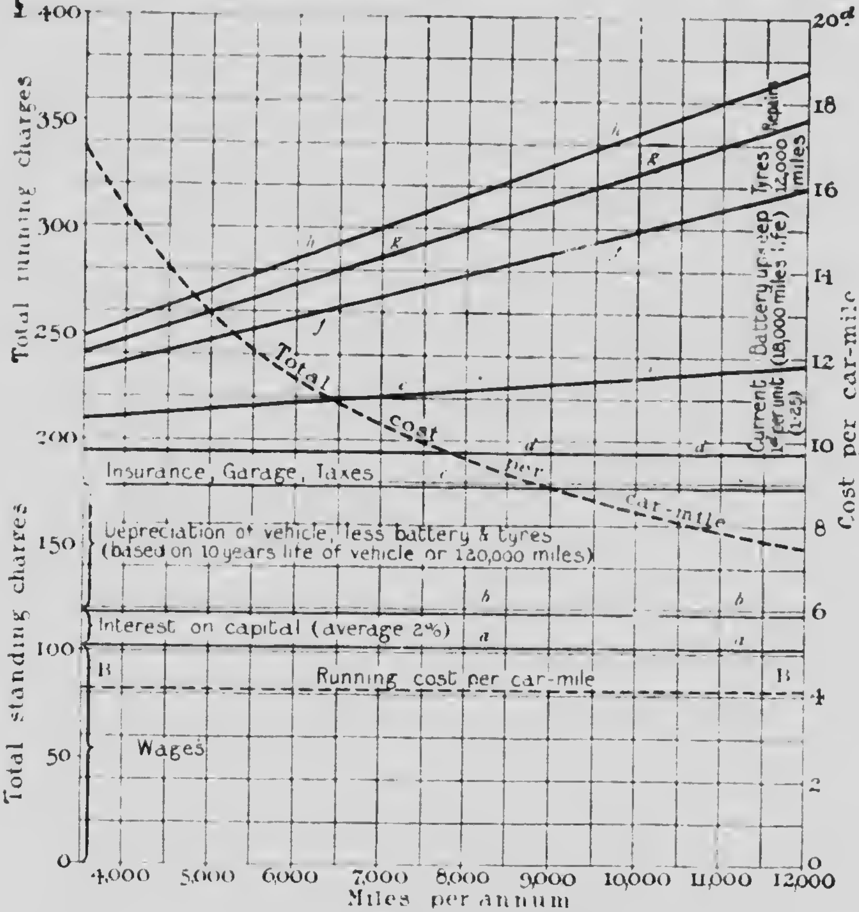


Fig. 1,626.—Total Annual Charges and Costs per Car-mile of running Electric Battery Vehicles

the result is very similar. Independently about 35 miles per day has been quoted as obtaining in New York.

The ordinates show the costs of operation and maintenance to two scales. The left-hand scale, to which the full-line curves must be referred, gives the total cost per annum of the various charges. These divide into two categories; the first, represented by the distances between the horizontal lines *a a*, *b b*, *c c*, and *d d*, are the standing charges which are independent of the miles the car runs, and consist of wages (£102) of the driver, interest on capital (£16), taken at 2 per cent., depreciation of vehicle (£20), excluding battery and tyres, which is taken at 10 per cent., and insurance, garage, and taxes (£16), also taken at 2 per cent. The total of £194 per annum is represented by the heavy horizontal line *d d*.

The second category comprises the charges which depend upon the distance run; these are represented by the distances between the sloping lines *e e*, *f f*, *g g*, and *h h*. The distance *d e* is the charge for current reckoned at 1d. per kilowatt-hour delivered to the vehicle; the next distance, *e f*, which it will be noticed is the greatest of the four, is the charge for battery upkeep, including renewals, reckoned on a life of 18,000 miles, which the battery makers guarantee for this service. The distance, *f g*, is the charge for tyres reckoned on a life of 12,000 miles, which is low, as the 10,000 miles guaranteed for petrol vehicles may well be increased to 18,000 miles for electric vehicles. The last distance, *g h*, is the repair bill, which is quite an appreciable item.

The right-hand scale, to which the two dotted curves are to be referred, gives in pence the cost per car-mile; the cars dealt with have a carrying capacity of 2½ tons, and a gross weight, loaded and including the battery, of 4·9 tons. The running cost per car-mile, line B B, is 4·1 pence, but the total cost varies from 7·5 pence to 16·8 pence per car-mile, according to the distance run in the year. It is interesting to note that the *running* cost is 55 per cent. of the *total* cost when the car runs 12,000 miles in the year, and falls nearly to 24 per cent. if the run is only 3,500 miles, thus showing the influence of the standing charges. It is still more interesting to note that the cost of the electric energy is only 23 per cent. of the total running cost, and therefore that this charge is only 12·5 per cent. of the total cost at 12,000 miles, and falls 5·5 per cent. at 3,500 miles. The bearing on the price paid for the electric energy is obvious.

Comparisons.—It being assumed that the total traffic on the streets and roads is a definite quantity, the question may be asked as to what existing vehicles the electric vehicle is to displace. The answer is that its greatest opportunity lies in superseding *horse-drawn vehicles* in the short-distance passenger, goods and other traffic, which forms so large a proportion of the urban and suburban traffic of our large towns. Its substitution would contribute appreciably to the relief of the congestion of the roads in the central areas, the handling of which is a very difficult problem for municipal engineers. An electric vehicle only occupies about half the space, and is quite as easily manipulated as a horse-drawn vehicle of the same carrying capacity. Many minor advantages of such a substitution are obvious, and need not be here referred to in detail, but one point of national importance should not be overlooked, and that is its influence on the food supply of the nation. If the fodder necessary for the sustenance of the horses is no longer required, the land set free can be used for the growth of human food, rendering the country as a whole less dependent on the supply of food from overseas, a necessity which has been brought home vividly to every inhabitant of this country by the great war, and the piratical activities of U-boats.

Electric Vehicles.—The other advantages of electrically-driven vans and lorries as compared with similar horse-drawn vehicles have been well summed up* as follows :—

(1) Cost of energy low, and no power consumed whilst at rest.
(2) Clean and sanitary.
(3) Speed double or treble that of horses with equal loads.
(4) Self-starting and easily controlled by semi-skilled labour.
(5) Short wheel-base requiring minimum space on streets and in garages.
(6) Reliability due to simple mechanism, equal to 95 per cent. of the working hours.
(7) Upkeep charges low.

Petrol-driven Vehicles.—The electric vehicle is better adapted for this supersession than the petrol-driven vehicle, whose ultimate sphere of action appears to be more properly in the direction of interurban and long-distance high-speed traffic in competition with railways than in dealing with the short-distance traffic with its numerous stoppages referred to in the preceding paragraph. The petrol-driven vehicle is essentially a high-speed vehicle, and low speeds can only be obtained at the cost of efficiency usually involving complications which are undesirable from other points of view.

The absence of noise and smell, so objectionable in a petrol-driven vehicle, is a distinct point in favour of the electric vehicle. Again, important commercial advantages are obtained from the much lower stresses of the working conditions in the electric vehicle. In petrol-driven vehicles the starting and speed-regulating stresses are very heavy, and to these must be attributed in great measure the ascertained fact that the life of the rubber tyres is about 80 per cent. longer in electric vehicles, whilst the chassis of the electric vehicle has a life double that of the chassis of the petrol-driven vehicle.

Passenger Traffic.—Where the traffic between points is sufficient to justify the capital expenditure there is no doubt but that the electrically driven tramcar is the cheapest method of dealing with the urban and suburban traffic of large cities. Next to the tramcar the trolley omnibus has been found to be cheaper than the petrol-driven omnibus, but in some large cities (e.g. London) the tramcars within urban limits are supplied with energy from underground conduits, and the trolley omnibus is not

* *The Electrician*, Vol. LXXVIII., p. 708, March 16th, 1917.

possible. In these cases the electric omnibus comes into direct competition with the petrol-omnibus, and there is an intermediate competitor in the petrol-electric vehicle described in the next section. Comparative figures for these competitors are given elsewhere.

For taxi-cab work in large cities, where the average speed is controlled to a great extent by other traffic, the electric cab has distinct advantages over the petrol cab. Most of these are included in the summary already given, but attention may be specially directed to the quickness with which it gets under way again when stopped by other traffic, and to the absence of the cranking-up nuisance; also to the fact that during these frequent and annoying stoppages there is no loss of energy by the engine being kept running idle. The same remarks, of course, apply to the electric automobile as compared with the petrol automobile when used for "runabout" work in the city.

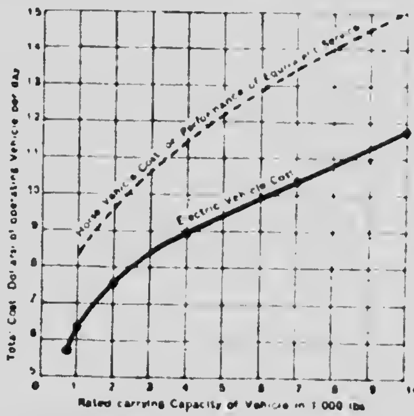


Fig. 1,624.—Daily Costs of running Horse-drawn and Electric Vehicles.

The rapidity with which an electrically propelled vehicle can be got under way is well illustrated by some remarks made by Lieut. S. Sladen, R.N., late Chief Officer of the London Fire Brigade, in a discussion at the Institution of Electrical Engineers. He pointed out that when a call is received, the electric vehicle starts in the very best trim, and the maximum speed is at once attained, whereas with other forms of traction, namely steam or petrol, a little time has to elapse before things become quite normal. He further remarked "that the rapidity of turn-out is absolutely unequalled by any other form of traction; it is not uncommon at an electric-motor fire station under ordinary service conditions for a turn-out to be effected in 7 or 8 seconds, whereas with other forms of motor a good turn-out is perhaps 15 seconds. As most of our runs for life-saving purposes are for distances of only about half a mile, the advantages certainly lie with electricity."

Costs.—The relative cost of working horse-drawn and electric vehicles are given graphically by the *Electrical World*, in the curves shown in Fig. 1,624, for vehicles of the different loading capacities marked in 1,000-lb. units on the abscissæ scale. The ordinates give, in dollars, the working costs per day, under the same conditions of loading and service for the different capacities.

The above figures were published in 1916, but some years earlier the

Massachusetts Institute of Technology conducted an investigation into the operating costs of electric, petrol, and horse vehicles, used for commercial purposes in the United States. The results were embodied by the *Scientific American* in a diagram from which Fig. 1,625 has been prepared. The data given refer only to urban traffic ordinarily handled by horse vehicles, and do not deal with the longer distance traffic for which the petrol vehicle holds the field, and in which the electric vehicle is a good second. Particulars of the cost per car-mile are given for four different

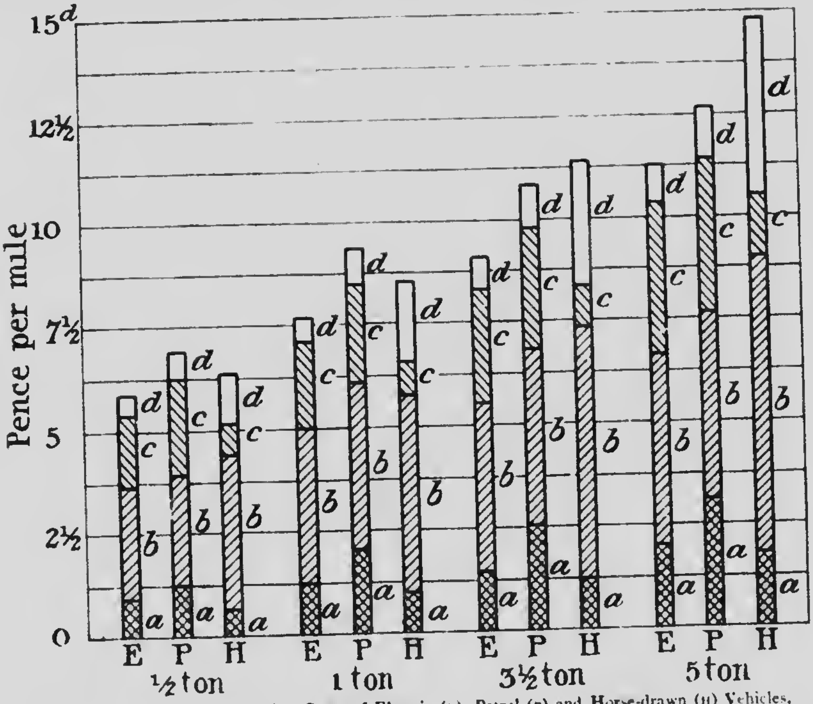


Fig. 1,625. Analyses of Running Costs of Electric (E), Petrol (P) and Horse-drawn (H) Vehicles.

load ratings of the vehicles used in each method, the results, electric (E), petrol (P), and horse (H), for each rating being placed side by side. The first section (*a*) of each column gives the standing overhead charges per mile, including interest on capital, depreciation, and insurance; the next section (*b*) gives the garage or stable charges together with the wages of the driver and, if used, helper; the third section (*c*) gives the maintenance charges including the tyres (or shoeing), repairs, battery maintenance (or veterinary charges), and lubricants; whilst the fourth or top section (*d*) gives the cost of the form of energy supplied, taking electric energy at 1½d. per kilowatt-hour, petrol at 8d. per gallon (which is very low as compared with this country), and fodder at £38 per head per year. In the ratings the ton is taken at 2,000 lb., and not at 2,240 lb. as in this country.

Fig. 1,526.—An early form of Petrol-electric Omnibus

The results, which are quite general, show that under the conditions and on the assumptions set forth, horse traction is cheaper than petrol for the lighter loads, the latter is cheaper for the heavier loads, and that electric-battery traction is cheaper than either for all the loads specified.

VI (iii.).—PETROL-ELECTRIC VEHICLES

In the other type of electric vehicle, in which the necessary energy is carried on the vehicle and not picked up *en route*, the energy is taken on board in the form of fuel, so that the equipment takes the place of the

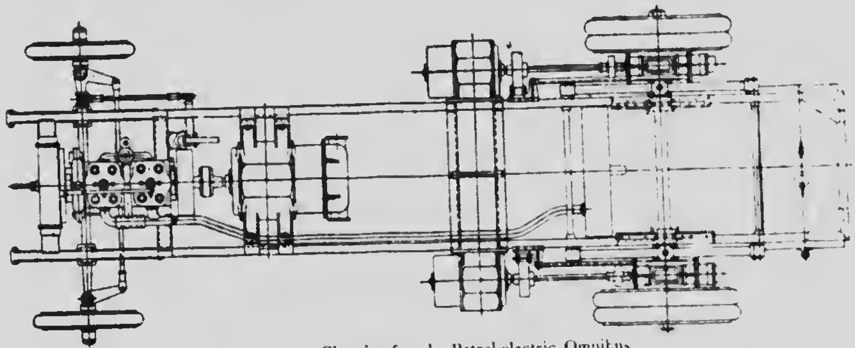


Fig. 1,627.—Chassis of early Petrol-electric Omnibus.

generating station and the transmission and distributing conductors of the great tramcar systems. The prime mover adopted is usually, but not necessarily, an internal-combustion engine burning petrol, and the great

Fig. 1,628.—A Tilling Stevens later Petrol-electric Omnibus.

advantage of the electric system is that it does away with the mechanically bad change-speed gears and their auxiliaries of the ordinary petrol-driven automobile.

The general method employed is very similar to the well-known Ward-Leonard system described in connection with electric railway work. The petrol engine drives a dynamo, the current from which is supplied to the motor or motors propelling the vehicle. The reasons why this roundabout system, with its several transformations, of conveying the energy of the fuel to the vehicle is a good engineering proposition are discussed elsewhere. One obvious advantage, in the present application of the method, is that the petrol engine can be kept running at its best and most economical speed, the output of the dynamo being controlled by altering the field flux and in other well-known ways, thus controlling the speed at which the vehicle is driven.

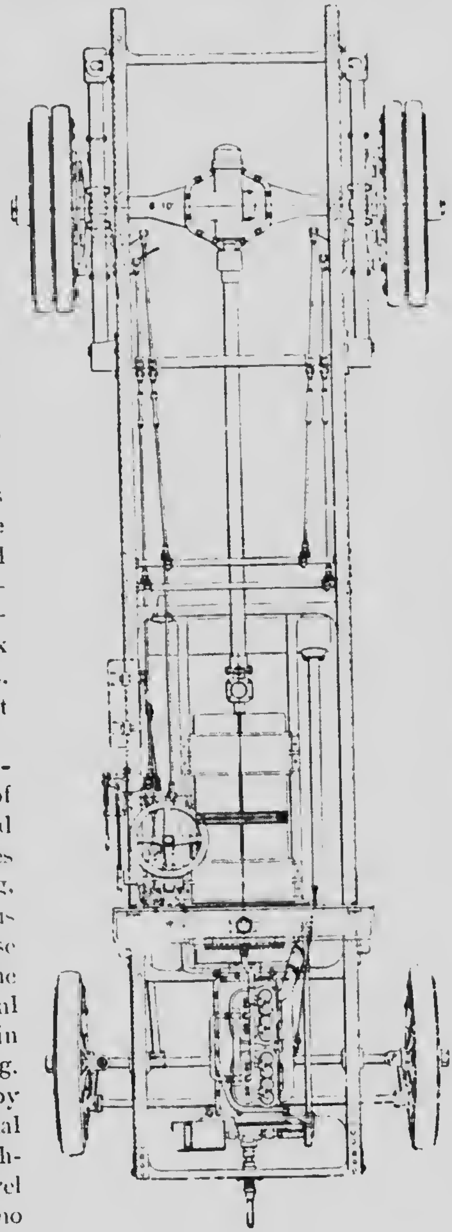


Fig. 1,623.—Chassis of Tilling Stevens Petrol-electric Omnibus.

The Tilling-Stevens Omnibus.—An excellent example of the general method is afforded by the petrol-electric omnibuses used by Messrs. Thos. Tilling, Limited, the well-known omnibus proprietors in London. These omnibuses also exhibit some interesting points in the gradual evolution of the type. Thus, in the early days, as shown in Fig. 1,626, the dynamo D, driven by the petrol engine from its usual position in front of the dashboard, was placed about level with the driver. This dynamo supplied current direct to two motors M attached to the outside of the frame of the chassis, and each driving through a transmission shaft and worm gearing, the rear wheel on its own side. An outline plan of the chassis showing the principal parts of the system is given in Fig. 1,627. The engine could develop 30 H.P. with a minimum speed of 350 R.P.M., but was automatically controlled to run up to 1,050 R.P.M. as a maximum, and the dynamo was a Stevens four-pole enclosed shunt-wound dynamo, with interpoles. The motors were series motors, each of 12 H.P., and could be put either in series or parallel by the controllers; the field resistance of the dynamo was also under control. The first of these omnibuses to be put on the road, after having run about 120,000 miles in regular service, was found to have effected

Fig. 1,630.—A Tilling-Stevens Petrol-electric Fire Escape.

a net saving of 1½d. per mile as compared with the petrol vehicles in the same service.

From this early type the advance was rapid and continuous, and we illustrate in Fig. 1,628 a Tilling-Stevens omnibus which, in 1911, some four years later than the omnibus just referred to, was the first of a large fleet of petrol-electric omnibuses which soon became familiar objects in the streets of London, especially in the southern suburbs.

In these omnibuses, as will be gathered from an inspection of a plan of the chassis shown in Fig. 1,629, the dynamo and the single motor used are nearly in alignment in the centre line of the chassis. The dynamo is driven through an ingenious spring coupling direct by the flywheel of the petrol-motor, which occupies the usual position under a bonnet in front of the driver. The shaft of the motor, which is a series-wound machine, is attached to the propeller shaft by a universal joint, and the propeller shaft drives the back axle with a worm and worm-wheel and differential gear of the usual type.

A still more modern example of the Tilling-Stevens petrol-electric vehicles is shown in Fig. 1,630, which illustrates a fire escape supplied to the London Fire Brigade in 1916, in which it is interesting to note that the power for elevating and training the ladder when the vehicle has been placed in position is supplied electrically from the dynamo to other motors

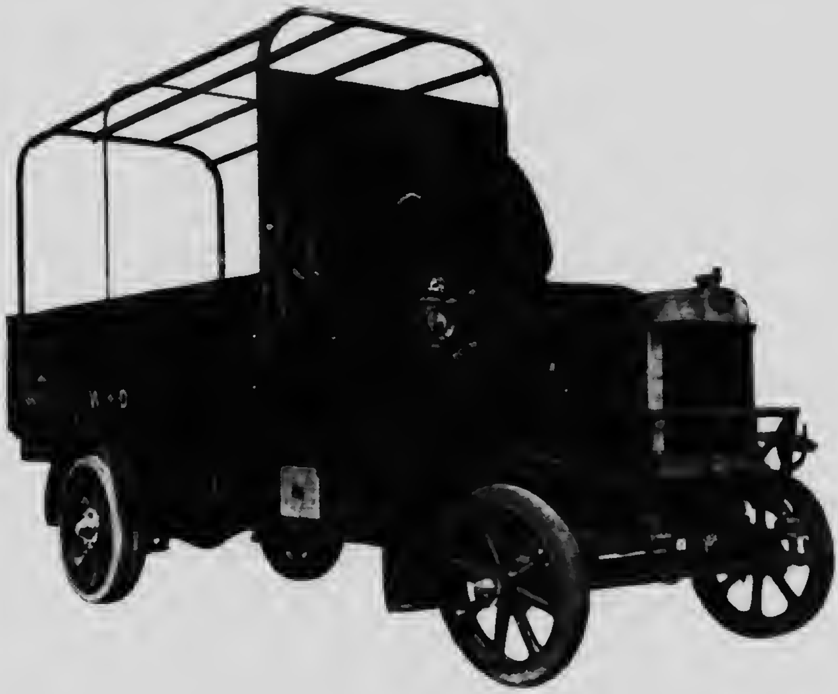


Fig. 1,631.—A Stevens 3-ton War Office Subvention Vehicle.

installed for this purpose. The method of controlling the propulsion motor is referred to later.

The Stevens Commercial Motor Vehicle.—Perhaps the most interesting application of the system was its adaptation for War Office purposes in vehicles which, although of the commercial motor type, had been designed chiefly for use in the great war. This necessitated that every part, down to the minutest detail, should be standardised so as to facilitate repairs in the event of any breakdown trifling or important.

The complete vehicle, known as the Stevens 3-ton War Office subvention vehicle, is shown in Fig. 1,631, as it was turned out by the Stevens Petrol-

Electric Vehicles, Limited, of which Mr. W. A. Stevens, an original worker in this subject, is the managing director. In addition to being a smooth

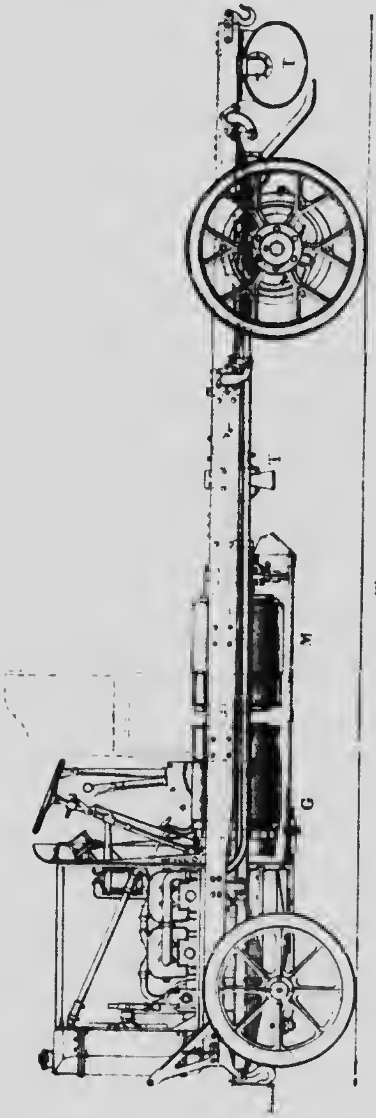


Fig. 1,632.

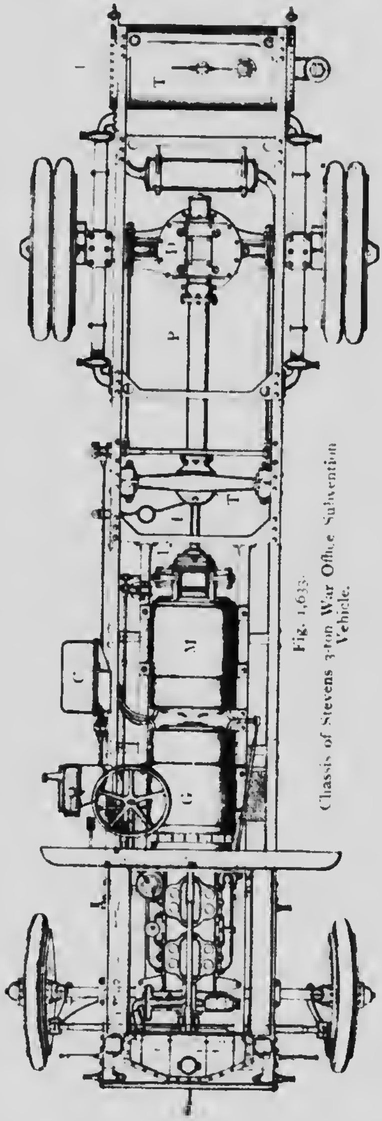


Fig. 1,633. Chassis of Stevens 3-ton War Office Subvention Vehicle.

running, reliable and economical three-ton lorry for transport purposes, it could provide when stationary, that is when its power was not being used for propulsion, a supply of electric energy for arc-welding plant, electric lighting, including searchlights, electric heating, motor driving, and secondary battery charging. The current available for these purposes was from 230 to 350 amperes at 110 to 70 volts, or about 2·5 kilowatts. If the electric power had to be delivered at a distance from the vehicle, the excitation of the generator, which was compound wound, could be varied, so that it was over-compounded to deliver at the distant point a constant voltage for all loads up to the maximum.

Drawings of the chassis in elevation and plan are given in Figs. 1,632 and 1,633. The store of energy is carried in the petrol-tank I at the rear

Fig. 1,634.—Controls of a Stevens War Office Petrol-electric Vehicle

of the vehicle. This tank has a storage capacity of 30 gallons, the fuel being drawn from it through the pipe by a pump to a feed tank fitted on the dashboard under the bonnet. The engine is a four-cylinder petrol engine of excellent design, and has the usual accessories, which lack of space prevents us from describing, as such details obviously lie beyond the scope of this book, which is concerned chiefly with the electrical equipment. The generator G is coupled to the engine shaft by flexible driving discs, which fulfil the functions of a fly-wheel and a clutch. The motor M is mechanically quite separate from the generator, but is in line with it, and the two are, of course, electrically connected through the controller box

C. which can also be made out under the driver's seat in Fig. 1,633. The various controlling levers, both hand and foot, and the steering gear, can be seen in front of the driver's seat in Fig. 1,634.

The motor shaft drives the propeller shaft P, through a universal joint J, with which the foot brake is ingeniously combined, this brake acting therefore directly on the motor shaft, whilst the hand brakes are applied as is usual to the rear or driving wheels of the vehicle. Between the universal joint box J and the worm gear and differential box D, there is interposed a "spherical torque and thrust tube joint" T, which allows a still more flexible connection between the propeller shaft P and the motor shaft by the introduction of the intermediate shaft I, driven direct by the universal joint.

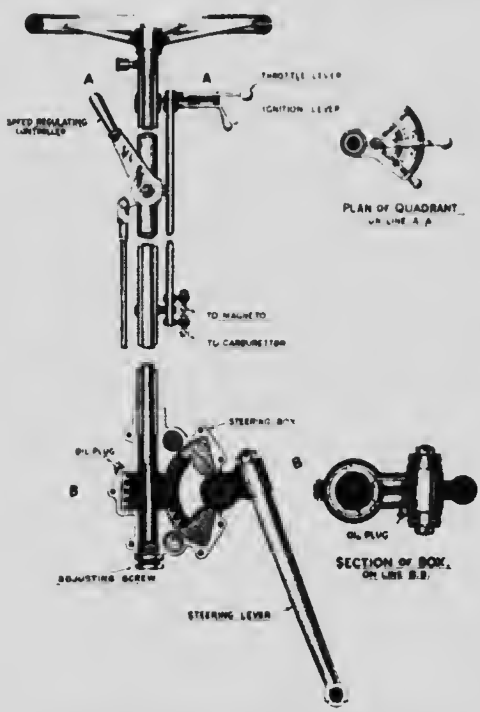


Fig. 1,635. Details of the Controls of a Stevens War Office Petrol-electric Vehicle.

The various hand and pedal controls are shown much more clearly on a larger scale in Fig. 1,634, which gives a perspective view of the dashboard with the floor of the driving platform removed, exposing the top of the generator and part of the top of the motor. The figure exhibits the whole of the controls within reach of the driver when seated in the driving position. Further details of the mechanism of the steering pillar and gear are given in Fig. 1,635, which is to a great extent self-explanatory.

The Thomas Electro-mechanical Transmission.—This is a still more complicated petrol-electric method of propulsion, inasmuch as at full load the electric transmission is entirely cut out, and the petrol engine drives the vehicle direct. It therefore more directly fulfils the function of taking the place of the ordinary, mechanically bad, speed-changing gear.

As in the cases just considered there are two electrical machines, but in the Thomas transmission these are mechanically as well as electrically coupled, and each of them can act as a generator or as a motor as may be required.

The general scheme of the transmission is shown diagrammatically in Fig. 1,636, taken from the *Electrical Review* for May 5th, 1911. The engine drives as its flywheel the casing D of a sun and planet gear-box, containing two sun pinions, W and W_1 and four planet pinions in two pairs P P and P_1 P_1, one of each pair, a P and a P_1 being upon the same idle axle carried by the box. The pinion W is on the driving shaft H H which passes through the hollow shaft K, and drives the road wheels through the usual gearing on the back axle. The shaft H H also carries the armature of a continuous-current machine C C_1, whilst the hollow intermediate shaft K, to which the pinion W_1 is keyed, carries the armature of the continuous-current machine B B_1. The two machines C C_1 and B B_1 are series wound, and their electric circuits are coupled through proper controlling devices.

When at rest the shaft H H is held stationary by the road wheels, and if the engine be started the sun and planet gearing will obviously drive the shaft K K backwards at a high speed, and if this shaft were un-

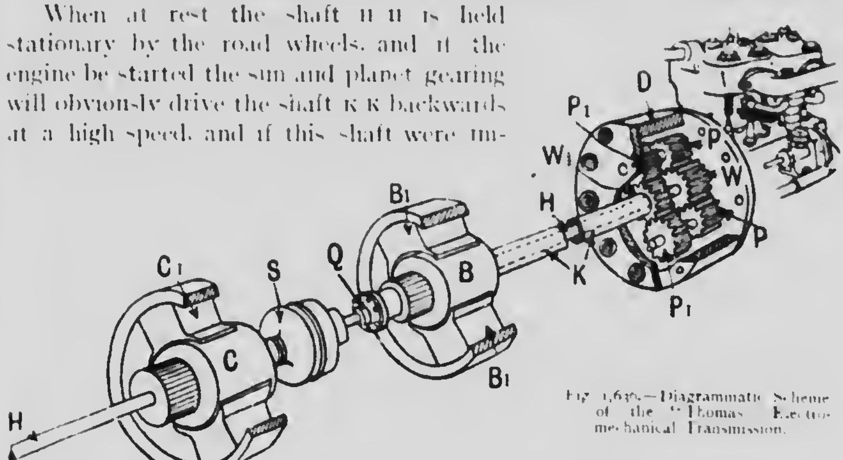


Fig. 1,636.—Diagrammatic Scheme of the "Thomas" Electro-mechanical Transmission.

loaded the engine would race unless throttled down. The machine B, however, acts as a generator, supplying energy to C, which acts as a motor, and B, thus absorbing energy, acts as a brake on shaft K, which slows down, and so compels the fly-wheel D to exert a torque on shaft H, to which the armature C adds a further torque, and the vehicle starts. It should be noted that the starting torque reaches the road wheels partly by mechanical transmission through the box D and partly by electrical transmission through the two machines. As H speeds up K slows down, till at a certain speed of H, depending on the gear ratios in D, the shaft K comes to rest, and the whole transmission is mechanical. From this point onwards, as the speed of H increases further, C acts as a generator, and B as a motor rotating the shaft K in the same direction as H. The speed of K increases more quickly than the speed of H, and at top speed the coupling Q is thrown in, coupling H and K together, and making the drive entirely mechanical, the electrical losses being eliminated since, whilst the speeds are approaching equality, the circulating current will be diminishing and will disappear at equi-speeds. Regulation for different speeds is obtained by using diverter

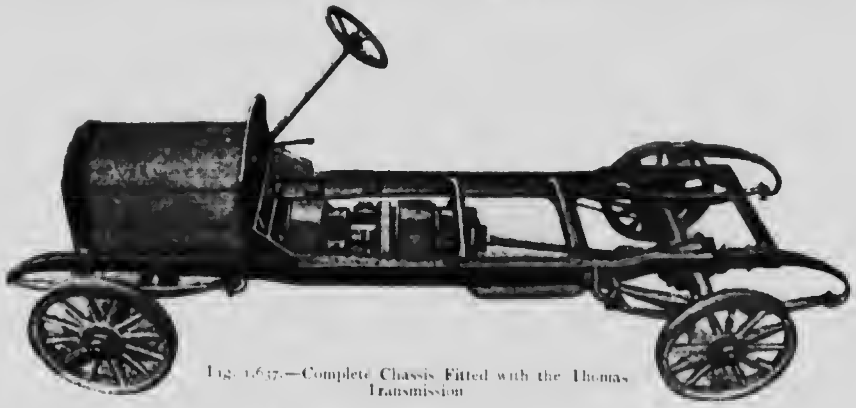
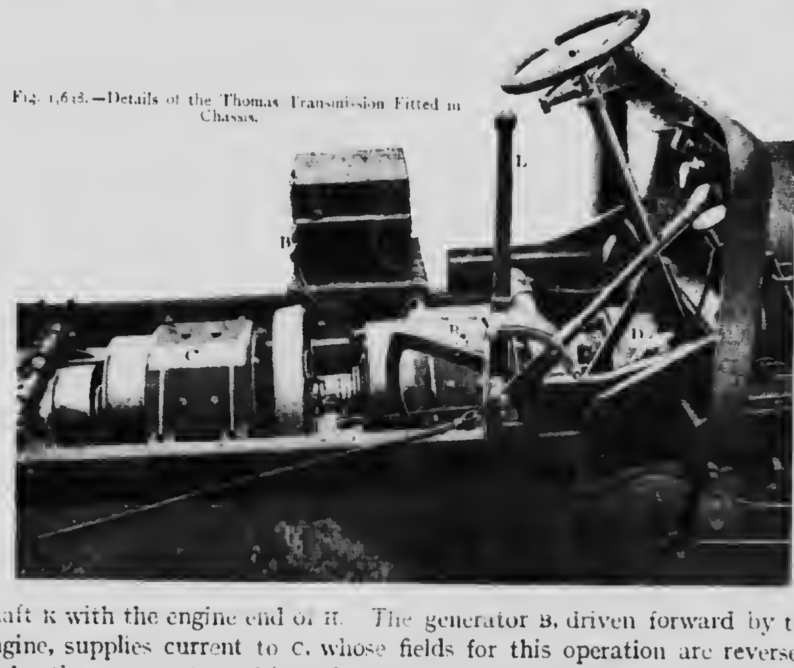


Fig. 1,637.—Complete Chassis Fitted with the Thomas Transmission

shunts on the field coils, and the field control is worked by a single lever having a neutral notch and ten speed notches.

For reversing the clutch S is disengaged, and the coupling Q engages

Fig. 1,638.—Details of the Thomas Transmission Fitted in Chassis.



shaft K with the engine end of H. The generator B, driven forward by the engine, supplies current to C, whose fields for this operation are reversed, and acting as a motor C drives the car in the direction reverse to the normal.

When the vehicle is running at full speed forward the machine $B B_1$ can be connected up as a shunt machine, and be used as a generator to charge a 12-volt battery which is used for car lighting, and can also start the engine by supplying energy to $B B_1$ joined up as a series wound motor.

An actual chassis fitted with the "Thomas" transmission is shown in Fig. 1,637, in which the two electrical machines can be clearly made out.

A still better idea of the system is given in Fig. 1,638, which is a side view of a portion of a chassis of a 30- to 40-H.P. lorry fitted with the system. The electrical machines B_2 and C are six-pole machines of the totally enclosed type. The controller, which is also totally enclosed, has been removed, but the lighting and starting battery B is shown as well as the change-speed lever L, with its notched quadrant. The outer casing of the sun and planet gear-box is seen at D, and some of the usual controls can be made out, but we have not space to pursue the subject further. Excellent results as regards economy and wear were obtained in an official trial of the system by the R.A.C. in 1911. Still later, in 1914, a London General Omnibus Company's bus was fitted with this transmission system, and after running 35,000 miles in the regular London service was found to have averaged between 10.5 and 11.0 miles per gallon as against 8.5 miles per gallon obtained under similar conditions by the Company's gear-driven vehicles.

Fig. 1,639.—The Thomas Transmission applied to Trailer Lorries.

Many developments of this transmission system have, as a matter of fact, already been worked out, but we can only refer to one here in which the chassis, being fitted with a much higher powered engine, is used as a tractor, taking charge of one, two or more trailers as shown in Fig. 1,639, in which 22 tons of cement are loaded on the three vehicles. Each of the trailers carries a motor similar to the second electrical machine C (Fig. 1,636) used on the tractor, and these motors are electrically connected through flexible cable couplings with the machine B on the tractor. The control is on the tractor, and the power is split, so that that vehicle is driven mechanically and the trailers electrically during the periods when large tractive effort is required. Whenever the tractive effort is less than can be dealt with by the leading vehicle alone, that vehicle is used as a simple tractor, the electrical transmission to the trailers being cut out.

Control of Petrol-electric Vehicles.—The principles of the control of the output of the generator, which runs at a fairly constant speed, and of the motor, which is to run at varying speeds, have been fully discussed in other parts of this book, and it is therefore only necessary here to indicate how they are applied in this particular case.

The general connections for such control are shown at the right-hand side of the diagram in Fig. 1,640,* which gives the connections for the Tilling-Stevens fire escape illustrated in Fig. 1,630. The generator G driven by the petrol engine is shunt-excited by the coil s_h, which is in series with the five resistances r_5, which can be successively short-circuited by the controller

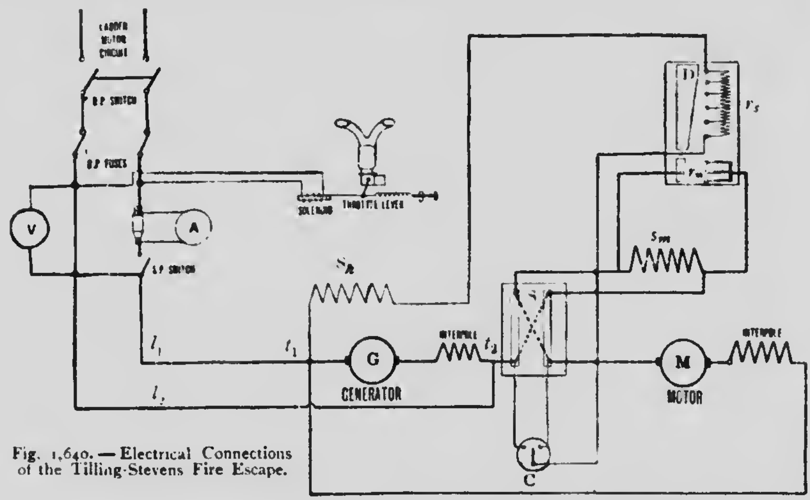


Fig. 1,640.—Electrical Connections of the Tilling-Stevens Fire Escape.

drum D, thus increasing the exciting current and the field flux and raising the voltage of the motor circuit as the load increases. There is the usual interpole magnet in series with the armature to assist the commutation. The voltage is further controlled by varying the speed of the engine, and therefore of the armature, by means of the throttle pedal. By this means the speed can be reduced from 1,400 to 350 R.P.M., and as, at the last-named speed, the generator is practically unable to excite its shunt-wound field magnets, the voltage falls to zero, and there is no current for the motor. At full speed and excitation the pressure is 300 volts.

The motor draws current from the terminals t_1 t_2, of the generator. It is series-wound, s_m representing the field-magnet coils, and there is an interpole magnet, also in series, for commutating purposes. As the load increases the contact drum D, if further revolved after it has removed all

* From the *Electrical Review*.

the resistance from the generator field circuit, brings resistances r_m into parallel with the motor field-coil s_m, diverting the current, weakening the field and controlling the speed as explained elsewhere.

For reversal of running the awkward arrangement of an ordinary petrol vehicle is replaced by the simple reversing switch S, which has three positions, "forward," "neutral," and "reverse." In the neutral position the circuit is broken and no current can reach the motor. For "reverse" running the excitation current is sent in the reverse direction through the magnet coils, thus reversing the direction of motion of the motor armature, as explained elsewhere.

The two-way change-over switch C in the generator field circuit is only required because the generator current is to be used for purposes other than propulsion. For ordinary running the lever is on the right-hand contact, and the shunt circuit of the generator is broken when S is in the "neutral" position, thus ensuring that no energy is used even for excitation purposes when the vehicle is standing still. It is in this case, however, that the generator current, if so desired, may be used for other work, and therefore the field circuit of the generator can be closed independently of S by moving the lever C on to the left-hand contact. Current can then be supplied from the terminals t_1, t_2, through the leads, l_1, l_2, to any stationary apparatus such as a searchlight, electric welding plant, etc., or as shown in Fig. 1,630 for raising and training the telescopic ladders of a fire escape. The usual instruments, fuses and switches are indicated, and in addition there is a shunt-wound solenoid electrically controlling the throttle-lever of the petrol engine and maintaining the voltage of the generator at a predetermined value independently of the load.

The same principles of controlling the propulsion circuits are used in the Stevens' War Office Subvention Vehicles, Figs. 1,631 to 1,635, but it is unnecessary for us to pursue the subject here, and we therefore do not give illustrations of them. It may be explained, however, that there are, as above, two controls (i.) a reversing switch operated in this case by a side-lever (*see* Fig. 1,634), and (ii.) a speed-control switch operated by the hand-lever shown in Fig. 1,635 as fitted to the steering column.

VI(iv.).—Other Applications

The preceding three subsections do not exhaust the services which modern secondary batteries can render to the vehicles running upon our roads and streets. It is obvious that a secondary battery can be a useful auxiliary for *lighting* purposes. When the car is running the necessary current for the lamps can be obtained from a small dynamo driven by the petrol engine, but if this only were available the lamps would go out when the engine stopped. A battery of secondary cells overcomes the difficulty. Such a battery can be charged by the lighting dynamo either during daylight hours when the lamps are not required, or in parallel with the lamps and when the engine is not running can supply current to the lamps.

A still further service can be rendered by such a battery, namely, to act as an *engine starter*. It has been remarked more than once in the preceding pages that one of the great defects of the petrol-driven vehicle is the difficulty of starting the engine by the ordinary method of "cranking-up" by hand. The lighting battery has a store of energy sufficient for this purpose if properly utilised. What is necessary is to connect the battery to a suitable motor so installed as to drive the engine for the few revolutions necessary for a good start.

We have not space to describe fully all the methods which have been devised for this purpose, but one excellent arrangement, designed by the Daimler Company, is shown in Fig. 1,641. The long shaft driven by the small motor M carries at its far end a friction wheel which can be pressed against the rim of the engine fly-wheel by depressing a pedal. When it is against the wheel the plunger switch *s* is depressed, closing the circuit of the battery and motor and starting the latter so that the shaft rotates. The friction wheel is released as soon as the engine starts up. The battery is a 12-volt (6-cell) battery, and can give a momentary current of over 100 amperes, which would give 1 horse-power on the shaft, quite sufficient for starting purposes if everything else is ready. The lighting dynamo is under the bonnet and is not shown.

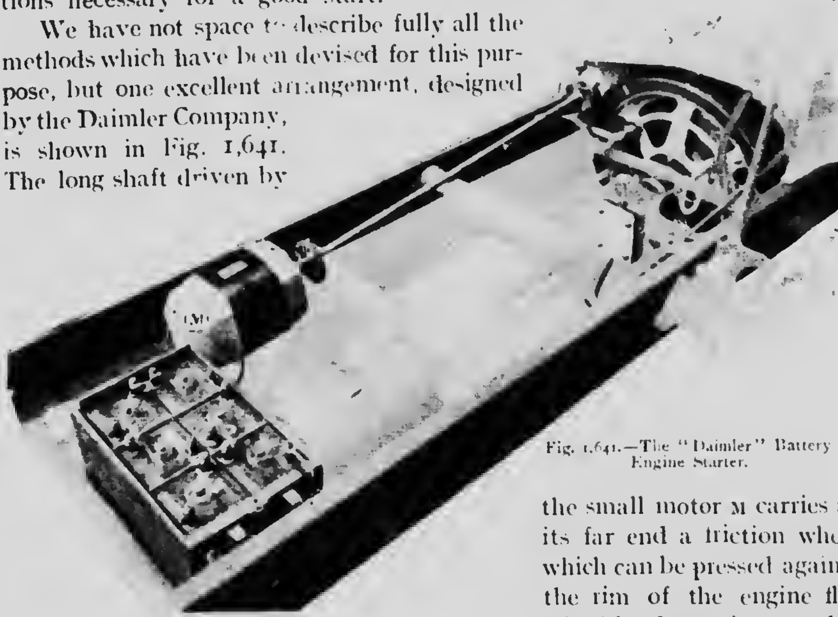


Fig. 1,641.—The "Daimler" Battery Engine Starter.

Attention may also be called to the fact that a small secondary battery can be used for *ignition* purposes, although at present the well-known magneto dynamo or "magneto" is much more widely used. Battery ignition, however, is a useful alternative in the event of anything going wrong with the magneto ignition, and is quite cheaply installed if a lighting battery be carried.

CHAPTER XV

ELECTRIC RAILWAYS

THE changing of the system of haulage from steam locomotives to electric locomotives or groups of distributed motors is one of the most interesting engineering problems of the present day, and we are still in the midst of the development. How far it will proceed no engineer can as yet confidently predict. Commencing with the electric equipment of some new and short urban lines in London and Liverpool as far back as 1890 and 1893, such urban and suburban lines which have been built since have, almost without exception, been planned from the first as electric railways. Meanwhile, some of the older suburban and interurban railways in this country have, either wholly or in part been equipped for electric haulage: A salient example for Londoners is the old Underground, which by the change has been converted from a road which one would only use on compulsion almost to a pleasant and enjoyable route. Up to the present, however, main-line electrification, as it is called, for other than suburban traffic, has not made much practical progress, although it has been the subject of much discussion. A start is being made by the London, Brighton and South Coast Railway Company with its main line to Brighton, and for many years the Lancashire and Yorkshire line between Liverpool and Southport and the Heysham branch of the Midland Railway have been run electrically. The Lancashire and Yorkshire line referred to is, however, strictly speaking a suburban line, and the Midland case is that of a somewhat small branch line only. It therefore remains generally true that main-line electrification has scarcely commenced in this country, though the more recent electrification of the metropolitan sections of the London and North Western Railway and of the London and South Western Railway have considerably increased the mileage for suburban or quasi-suburban traffic.

Abroad, however, and especially in the United States, this development has gone forward more rapidly Following the lead of the London and Liverpool examples mentioned above, there came a period of rapid development of electric traction on suburban railways as distinct from tramways or street railways, as they are called in America. This was followed by a serious grappling with the problem of main-line electrification, the most notable, though not the only, outcome of which was the electrification of the main line of the New York, New Haven and Hudson River Railway, one of the trunk lines in the Eastern States. Simultaneously on the Continent of Europe, and in other parts of the world, a great number of lines, mostly short, have been projected and equipped for electric traction, and there have been some cases of conversion of existing lines.

A great obstacle to the more rapid development of the change from steam to electric traction on main-line railways is the amount of capital sunk in steam locomotives and in the special equipment of large works for their repair and the maintenance of the supply. Also there is the degree of perfection to which these tractors have been brought, and the vast artisan army thoroughly familiar with them and all problems connected with their working.

On the other hand the steam locomotive system is far behind the best systems of electric traction in its efficiency in the utilisation of our none too large supplies of coal fuel, besides making no use of the water power which is running to waste in so many places. The necessity for conserving our supplies of fuel has been insisted upon for many years since it was realised that the quantity available is not inexhaustible and that in this direction we are squandering capital.

The great war has driven home another aspect of the problem, the necessity for obtaining the greatest output from the fuel which is being expended. As shown elsewhere the output actually obtained under the best conditions is no very brilliant achievement. In connection with the influence of railway electrification on both conservation and efficient utilisation of our sources of energy, the President of the American Institution of Electrical Engineers gave, early in 1918, some interesting figures. He estimated the horse-power of the steam railway locomotives in the United States at 25,000,000, as against 13,000,000, the horse-power of all the central and private electric generating plant in the country. The coal consumption of the locomotives was stated to be 150,000,000 tons per annum, and of this two-thirds could be saved by electrification, since, under average conditions, the steam locomotive requires 6 lb. of coal per horse-power hour, whilst the same trains could be hauled electrically with a consumption of 2 lb. per horse-power hour if the energy were supplied from large central generating stations, account being taken in this estimate of all the losses in generation, in transmission, and in the motors on the trains.

The principles underlying electric traction on railways are the same, and the methods adopted for the solution of the problems presented are similar to those met with in electric tramway working, and it will not therefore be necessary to restate them in full detail. The outstanding differences between the two are due to the fundamental change in the external conditions, based on the fact that the track of a street tramway is open to all and sundry, and the safety and convenience of those who have a right of user of the road have to be considered, whilst, on the other hand, a railway runs, at any rate in this country, on private property from which trespassers can be excluded, or must accept any risks incidental to their trespass. This fundamental difference leads to many changes in the consequent conditions. For instance, the speed limit permissible depends only on engineering and commercial considerations. Again, in addition to the frequent stoppages of suburban traffic, long non-stop runs are possible, the distances between the stopping places depending entirely on the traffic available or which may be induced. Other differences will readily occur to the reader, many being directly traceable to the enclosure and private character of the track and stations.

Following the general plan adopted in the preceding chapter, the present chapter will, on the whole, be devoted to a description of the methods adopted, and details of the equipment, for supplying energy to railway trains and of matters arising therefrom.

THE SUPPLY OF ENERGY TO RAILWAY TRAINS

I.—SUMMARY OF METHODS

As in the cases already considered, the energy required for the propulsion of railway trains may either be picked up from moment to moment, as and when required by the moving train, or be carried on the train or locomotive and renewed at convenient intervals. We are, of course, concerned only with electrical principles and details, and, adopting the same system as heretofore of classification, we may summarise the methods at present in use as follows :—

(A) *Energy, external or picked up.*

(i.) From a third, or a third and fourth, rail laid alongside or between the running rails, the rails themselves being the return circuit in the first case.

(ii.) From an overhead insulated conductor or conductors suspended over the track.

(B) *Energy, internal or carried.*

A FUEL-DRIVEN ENGINE, carried on a suitable truck, acts as a prime mover driving an electric generator, from which electric power is conveyed to motors which drive the train.

So far as the writer is aware, secondary batteries have not hitherto been used for long-distance railway traffic, though experiments have been made with them on suburban lines. It will also be noticed that sections A (ii.) and A (iii.) of the tramway classification have, for obvious reasons, also disappeared.

In the above classification, nothing has been said as to the type of electric energy to be utilised. As a matter of fact, either (*a*) continuous currents, or (*b*) alternate currents can be used in each case, and for our purposes it will as a rule be convenient to treat this as an additional and partly as a cross classification, and to deal with the two types to some extent separately. A few more detailed, but brief, historical and general notes will be a fitting introduction to the technical sections which follow.

II.—EARLY ELECTRIC RAILWAYS

As mentioned in the introductory remarks, the first electric railways built were the City and South London Railway and the Liverpool Overhead. Both these used the third-rail system with return circuits through the rails and earth. There was, however, one great physical difference between them, namely, that the first was a deep-level underground line, and that the other was a surface railway, meaning by that term a railway which is laid on or close to the surface of the ground, and including in it the overhead and shallow underground railways which often at some part of the system are also actually on the ground level. The distinction forms a convenient sub-classification for our purpose.

Tube Railways.—A brief description of the first tube railway, the City and South London Electric Railway, as built and originally equipped, will be of interest, both by way of contrast to and also of similarity with its descendants. The completion of this line marked a distinct advance in the application of electric locomotion to ordinary railway passenger requirements, especially in large and densely populated districts. It was formally inaugurated by Queen Alexandra, then Princess of Wales, on November 4th, 1890, and opened for public use on December 18th of the same year.

The original line, which was 3½ miles long, and is still used, extended from the Monument in the City of London to Stockwell, on the south side of the Thames. There are two distinct tunnels, one for the up and the other for the down line, so that collisions between trains travelling in opposite directions are impossible. The tunnels consist of iron tubes following the direction of the main thoroughfares above, but at a distance of 60 to 70 feet below the surface, so that all interference with gas or water pipes, sewers and subways, etc., is avoided, as well as disturbance of the roadway during the progress of the work. As a rule, the tunnels run side by side, but where they pass under the Thames one is above the other. The railways of which it is the forerunner and the type are at present peculiar to London, and are rendered possible by the geological features of the Thames valley, which contains, under the area occupied by the modern town of London, a thick bed of blue clay through which the engineer can easily bore at any convenient depth. As water-bearing strata and other difficulties, however, are met with, the actual boring operations were made an engineering possibility and success by the invention of the Greathead shield, which, by the use of compressed air, keeps back the water whilst the bore-hole is being lined with a cast-iron tube built up from segmental castings, section by section, as the boring progresses. The description in detail of the method of boring belongs to civil engineering, and would take us too far from the main object of this book. Incidentally, however, it may be mentioned that it gives a great choice of route to the projectors of the railway, who, by carrying under main roads at a sufficiently great depth to avoid other works, can also avoid the necessity for purchasing freeholds, wayleaves, etc., except at the actual stations. From the engineering point of view, it also gives greater freedom in the choice of gradients than a surface railway.

The City and South London track has many severe gradients and curves, some of the former being as heavy as 1 in 25. The ventilation, a serious difficulty at such a depth, was intended to be automatic, since each train nearly fills the cross-section of the tunnel and drives the air before it as it advances, drawing in a fresh supply from the station which it has just passed. Although, however, the air is circulated by the movements of the trains, as a method of ventilation the action is not sufficient for modern requirements.

The generating station was at Stockwell, and will be found described in a previous edition of this book. There were three dynamos, constructed by Messrs. Mather and Platt, of the original Edison-Hopkinson type (*see* Vol. I., Fig. 498, page 524), each capable of giving 450 amperes at 500 volts, or 300 horse-power. Each dynamo was driven by a vertical compound engine capable of indicating 375 horse-power. Two of these engines and dynamos were sufficient for the ordinary requirements of the line, the third being kept in reserve. From the dynamo-room the current was led by four feeding mains to distributing boards in the signal boxes. These mains were Fowler-Waring cables, each with a copper conductor of 61 strands of No. 14 wire insulated with patent insulating material and lead sheathed. From the signal-boxes the current was conveyed to the feeding points on the working conductor. The latter consists of a specially rolled steel rail of good conductivity carried on glass insulators between and about one inch below the level of the main rails. Each length was joined to the succeeding length by a fishplate and bolts in the usual way, but electrical continuity was insured by bonds of laminated copper strips riveted to the steel conductor, a system which we describe elsewhere (*see* pages 1573 to 1585), and which has since been universally adopted. It was first used for heavy railway work in this case. The working conductor was divided into sections which could be isolated for testing or other purposes. After the current had passed through the locomotive, it returned by means of the ordinary running rails, which were likewise bonded together with copper strips. The methods of insulating the conductors and other details, which have been widely followed in more recent practice, will be described later.

The locomotives were, from an electrical point of view, the most interesting part of the railway. One of these is depicted in Fig. 1,642. Each locomotive was driven by two motors whose armatures were built upon the running axles of the wheels, so that the complication and loss attendant on the use of reducing gear were avoided. The field magnets, which were very massive, were supported partly by the axles and partly suspended from the frame of the locomotive, and thus had a certain amount of freedom of angular motion about the axle. The magnets were series wound,

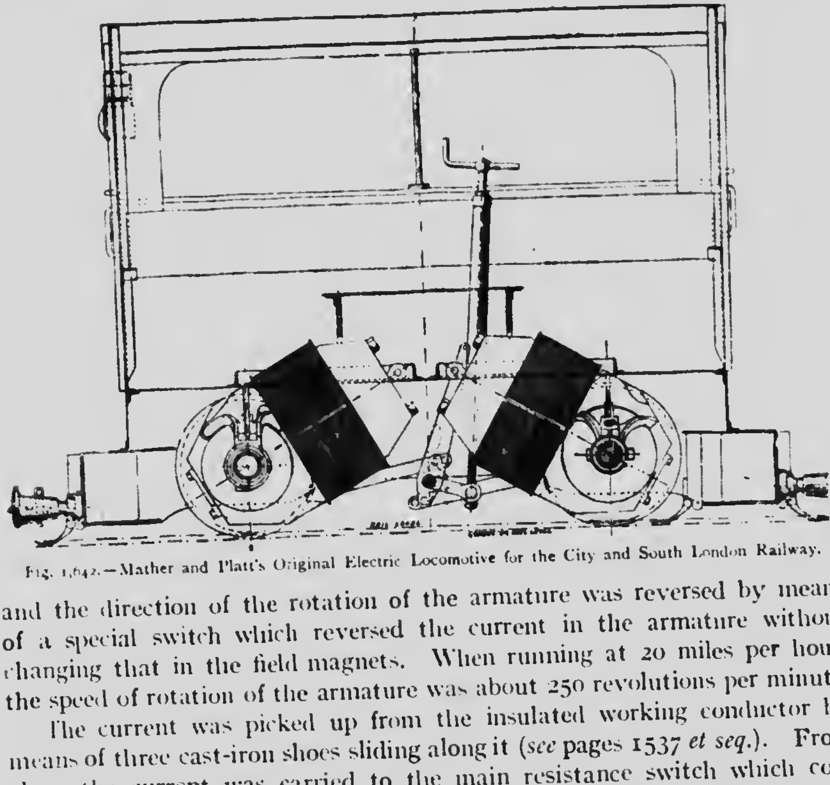


Fig. 1,642.—Mather and Platt's Original Electric Locomotive for the City and South London Railway.

and the direction of the rotation of the armature was reversed by means of a special switch which reversed the current in the armature without changing that in the field magnets. When running at 20 miles per hour, the speed of rotation of the armature was about 250 revolutions per minute.

The current was picked up from the insulated working conductor by means of three cast-iron shoes sliding along it (*see* pages 1537 *et seq.*). From these the current was carried to the main resistance switch which controlled both motors. The regulating resistances were in series with the motors, and were gradually cut out as the speed increased. After passing the motors, the current returned by means of the wheels to the running rails. It is of interest to note how many of these details have been closely followed in modern tramway and railway practice.

Fourteen of these locomotives were originally supplied for the service of the line, but others were soon added. Each locomotive weighed 10 tons, and was capable of exerting a tractive pull of 3,000 lb. and running at a speed of 25 miles per hour. A train consisted of a locomotive and three carriages, each constructed to carry thirty-four passengers. The train was lighted by glow lamps supplied with current from the mains. At the busy part of the day, in the morning and evening, sixteen to seventeen trains were run per hour each way, and in the first year over 5,000,000 passengers were carried. In the same year the average mileage of each locomotive in regular use was over 27,000, which was considerably above

Fig. 1,643.—The Liverpool Overhead Railway in 1893.

the average of a well-equipped steam railway. The success of this line led to the projection, and the opening in 1900, of the Central London Railway, followed by the network of tube railways, chiefly north of the Thames, which were opened some years later and are referred to below.

Surface Railways.—Besides leading to the development, in due course, of other tube railways, the success of the City and South London Railway bore more immediate fruit in the projection and opening for traffic in 1893 of the Liverpool Overhead Railway. The railway marked the completion of a scheme which for more than forty years had been under the consideration of the Mersey Dock Board, and the development of electric traction in the latter part of the period undoubtedly led to its practical accomplishment.

The railway was originally about six miles long, and traversed the whole length of the famous Liverpool docks. It is constructed almost entirely of wrought iron, and consists generally of plate-iron girders supported upon channel-iron columns and carrying an iron flooring upon which the permanent way is laid direct without the usual ballast. There are several interesting engineering details in connection with its construction, which, however, scarcely come within the scope of this book. The general appearance of the railway,

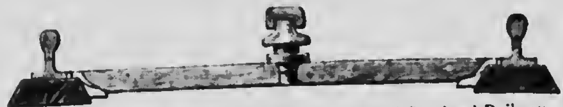


Fig. 1,644.—Conductor and Track Rails, Liverpool Overhead Railway.

which is of historical interest, is shown in Fig. 1,643, which is from a photograph of a station, and shows a cross-over junction. A prominent feature in the figure is the third-rail conductor, which was carried centrally between the running rails on cross timbers, as shown in Fig. 1,644, and was very similar to that used on the Central London Railway. It consisted of inverted channel steel S supported on porcelain insulators P, as shown on a larger scale in Fig. 1,645, which is drawn to scale and gives a good idea of the dimensions adopted. The line L indicates a lead pad inserted to deaden vibrations. The insulators were also similar to those used in London, but had to be of porcelain instead of glass, because in Liverpool they were exposed to our damp climate. The upper surface of the conductor was raised seven-eighths of an inch above the upper surface of the running rails to allow the collecting shoe to pass over

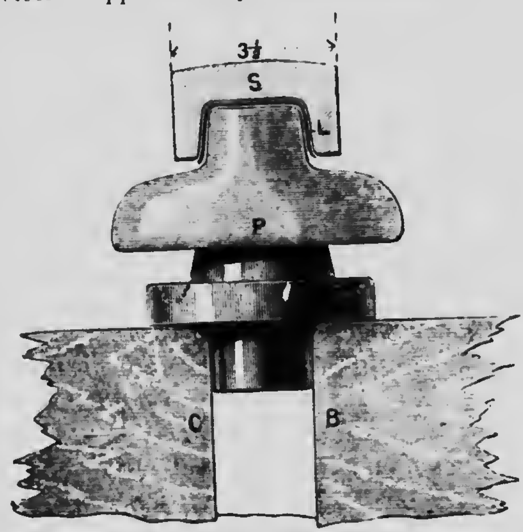


Fig. 1,645.—Conductor Rail and Insulator.

the latter without touching at the cross-overs, where for this purpose the conductors were bent parallel to the running rails, as shown by the thick black lines A in Fig. 1,646, where the running rails are represented by the thin double lines. The shape of the collecting shoe, which enabled this crossing over to be safely accomplished, is shown in Fig. 1,647; it will, of course, be realised that, as the running rails were used for the return circuit, if the shoe should make contact with them whilst touching the insulated conductor, the electrical system would be short-circuited with disastrous results. The vertical clearance of seven-eighths of an inch was found sufficient in practice to prevent the short-circuit, especially as, owing to its shape, the collector was always in contact with the conductor during the transit, and thus the main circuit was not broken and the danger of an arc flashing over was avoided. To increase the conductivity of the return circuit the running rails were bonded to one another and to the iron structure.

Fig. 1,646.—Running and Conductor Rails at a Cross-over.

A train consisted of two carriages, permanently coupled together, and instead of a separate locomotive, as used on the City and South London Railway, the motors were carried one on each of two separate bogie trucks. These trucks were placed one under the front and the other under the rear end of the train, so that the train could be run from either end, as is now common practice but was an innovation at the time. One of these bogie trucks is shown with the motor mounted on it in Fig. 1,648. The motor, like the London ones, was bipolar, but was of the double magnetic-circuit type widely used at that time and fully described in our historical section (e.g. Fig. 566, page 596, Vol. I.). The armatures of the motors were built on the running axles, thus saving gearing, and 10 revolutions of the axle per minute gave a speed of one mile per hour; the maximum speed was specified to be 26 miles per hour, for which the motor speed was 260 R.P.M. The motors

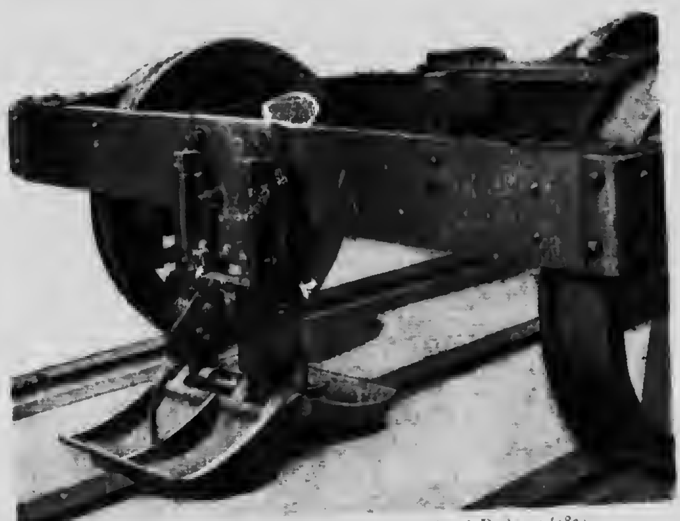


Fig. 1,647.—Collector Shoe, Liverpool Overhead Railway (1893).

were series wound, and with a current of 80 amperes each gave a tractive pull of 1,060 lb. The line voltage was 500 volts.

The electrical equipment was provided by the Electric Construction Corporation, Limited, to the designs of Mr. Thomas Parker. The signalling was automatic.

Continuing our historical retrospect, later in the same year (1893) as that in which the Liverpool Overhead Railway was opened, a third-rail overhead railway was erected at the Chicago exhibition. This, however, was entirely intramural, and erected for exhibition purposes. It was followed by the Metropolitan West Side Elevated Railway of Chicago. But it was not till 1899 that the electrification of railways, as distinguished

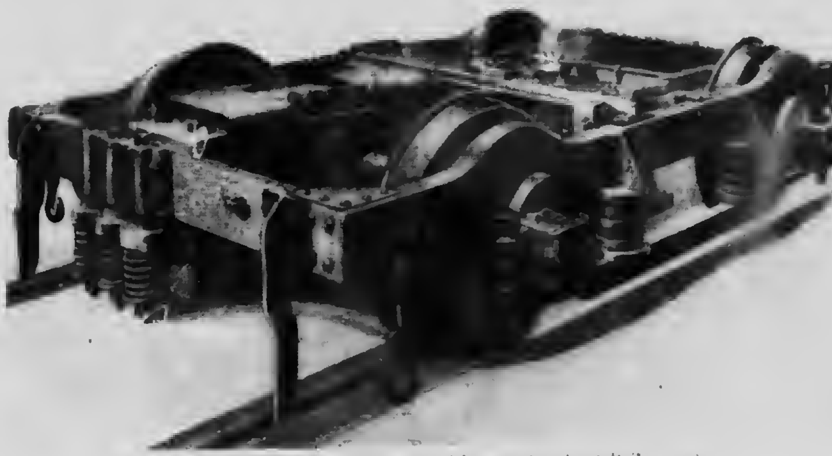


Fig. 1,042.—Bogie Truck with Motor, Liverpool Overhead Railway, 1893.

from tramways, was taken up in Amer[illegible] In February of [illegible] the stockholders of the Manhattan Elevated Railway in New [illegible] to change over the equipment to electr[illegible] from steam [illegible] which it had been [illegible] since its opening [illegible] Two years [illegible]ter the electrification was completed, and [illegible] railway work [illegible] to have entered upon its present stage [illegible] as continu[illegible] is concerned. As [illegible] some historical [illegible]st, we [illegible] view of one of the Manhattan station[illegible] reprod[illegible] taken at the time of the completion of [illegible] Fig. 1,043 it shows a cross-over, and [illegible] two [illegible] be [illegible]pared. The chief apparent difference [illegible] conductor rail outside the running rails instead [illegible] there are, of course, other differences in the details, ow[illegible]ter develop-

Fig. 1,644.—A Cross-over on the Manhattan Elevat ments and the change in the conditions. Some of these will be referred to in subsequent pages.

III.—THE "THIRD-RAIL" AND "THIRD- AND FOURTH-RAIL" SYSTEMS

In designing the conducting rails and their insulating or other supports for an enclosed railway, the conditions allow much more freedom than is possible with street or public-road systems, inasmuch as the safety from electric shock of anyone walking along the track is only a secondary consideration, and may sometimes be quite disregarded. In the historical retrospects it will be noticed that the insulated conductors were, to all intents and purposes, practically exposed and unguarded, and were designed chiefly for ease and simplicity of construction having regard to the electrical function they were to fulfil.

Materials for Rails and Supports.—The material used for the *conductor* is usually a low carbon steel, the superior specific conductivity of copper being much more than counterbalanced by its high price, which need not be faced, since there are now no special difficulties in supporting the increased weight of the much cheaper iron necessary to obtain the required total conductivity. In other words, the higher specific resistance of iron can be counteracted by a much larger increase in the cross-sectional area of the conductor without approaching at all near to the cost of the equivalent copper or aluminium conductor, and the difficulty of supporting the increased weight per unit length may be disregarded; in fact, the larger cross-section has an additional advantage in increased stiffness.

The examples already given in the foregoing historical notes also show (*see* Fig. 1,645) that the increased weight has still another advantage inasmuch as the inverted channel steel conductor was heavy enough to be carried on the insulators without any device to keep it in its place other than its own weight. The shape of the cross-section adopted in many more modern cases, however, does not allow this simple result to be attained, and, as will appear in the sequel, it has been necessary to redesign the insulators with the view of providing some means of binding the rail either loosely or rigidly to its insulated support.

Experiments show that a very low carbon steel has a higher specific conductivity than the steel used for traffic rails. Such steel would not be serviceable for the heavy wear of the running rails, but is quite good for the less strenuous service of a conductor rail. The composition adopted, after a careful investigation, for the conductor of the Manhattan Railway is shown in the following table, to which there are added, for convenience of comparison, similar particulars of the conductors used in some typical subsequent cases :—

TABLE XXIV.—COMPOSITION OF STEELS USED FOR CONDUCTOR RAILS

Constituents.	Percentage.			
	Manhattan Railway (1901).	Central London Railway (1900).	L. & N W Railway (London) (1914).	L. & Y. Railway (1915).
Carbon	0·073	0·030	0·044	0·080
Manganese	0·341	0·33	0·130	0·220
Nickel ...			0·255	
Silicon		—	0·030	0·022
Sulphur ...	0·073	0·045	0·020	0·026
Phosphorus	0·060	0·052	0·011	0·034
Resistance (Copper = 1) ...	8·0	7·3	6·5	6·5–7·0

The conductor of the Manhattan Railway had about eight times the specific resistance of copper, but was by 20 to 30 per cent. a better conductor than the steel of the ordinary traffic rails.

The table also gives the composition of the steel used for the conductor rail on the Central London Railway (opened in 1900). This steel contained less carbon, and has a still higher conductivity, its specific resistance being 4·94 microhms (inch measure) at 20° C., or about 7·3 times that of copper.

In the next column will be found the composition of the conductor rails employed in the much more recent (1914) electrification of the London lines of the London and North Western Railway. This conductor, weighing 105 lb. per yard, is also made of a special low carbon steel. The specific resistance is about 6½ times that of copper, and the rail is equivalent to a copper conductor of about 1·4 square inch in cross-section. It is interesting to compare this composition and conductivity with those of the earlier Manhattan steels of 1901 and the Central London steel given in the table. The result is higher conductivity and probably greater hardness, owing to the use of nickel. The last example is that of the steel used by the Lancashire and Yorkshire Railway on its Manchester and Bury section in 1915. It has a higher carbon content than any of the others and less alloyed metal, but its resistance is only from 6·5 to 7 times that of copper.

Another advantage of steel as compared with copper of equivalent conductivity is the much larger contact surface offered for transmitting the current to the moving train. Moreover, as the material is cheap, it is customary to use a section of still higher conductivity than would be commercially possible with copper, thus reducing the cost of the feeder cables.

The material used for *insulators* is either glass, where the conditions permit, or porcelain, or some form of artificial stone which can be readily moulded to the desired shape in the process of manufacture. The prevailing and even the exceptional atmospheric conditions in the locality where the insulator is to be used must obviously be carefully studied.

Permanent Way.—Detailed descriptions of the construction of the permanent way of railways in general obviously lie beyond the purview of this book, and it is not our intention to deal with such a big subject. The *tube railways* in London, however, are so essentially electrical railways, and are so unique, that a very brief reference to some non-electrical engineering details may be of interest to others than Londoners, and will form a fitting prelude to the further consideration of "third-rail" and "third- and fourth-rail" systems.

The general appearance, so familiar to Londoners, of the platform

Fig. 1,650.—A Typical Tube Station on the Central London Railway.

of one of these railways is shown in Fig. 1,650, which is a reproduction from a photograph of the Queen's Road Station on the Central London Railway, and which may be taken as typical of many others in all parts of London. The exit end of the tunnel between the stations, which is 11 feet 6 inches in diameter, is seen at the end of the platform on the right, and the streak of light across it is caused by the headlight of an approaching train.

The method of construction of this tunnel has already been explained (*see* page 1514). A clearer idea of the details of construction will be obtained from Fig. 1,651, which shows the interior of the completed tube with the track and third rail in place. The figure shows the successive tube rings built up of segmental castings, the joints between the segments being

Fig. 1,651.—The Interior of a London Tube Railway.

staggered in adjacent rings, these adjacent rings being bolted together as shown. The three rails are supported by transverse sleepers, and as the depression between the rails due to the curvature of the tube is not filled in, planks are laid across the sleepers so that the engineers and attendants can walk along the tunnel. The low-voltage continuous current feeders are supported on hooks on the right-hand side, and on each side of the tunnel the high-voltage (5,000 volts) feeders which supply energy to the sub-stations are carried on the special brackets shown in Fig. 1,652. These brackets are bolted to the flanges of the main castings and are protected by an iron shield, which can be readily removed when necessary. In this figure two cables are shown, each containing three insulated conductors for the three-phase supply.

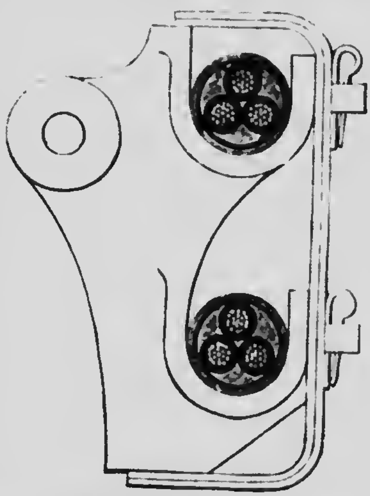


Fig. 1,652.—High-tension Cables and Support, Central London Railway.

As considerations of space do not allow us to describe fully the interesting details of track, station design and construction of these unique railways, we give here, in Fig. 1,653, a cross-section of a station of one of the more recent examples, the Baker Street and Waterloo Railway, more commonly known as the "Bakerloo Tube." It will be noticed that the station section is, like the running section, a tube constructed generally in the same way, but of a larger diameter of rather more than 21 feet, the vertical centre lines of the two being 5 feet 3 inches apart. The figure has the principal dimensions marked on it, with additional interesting information of certain details of construction.

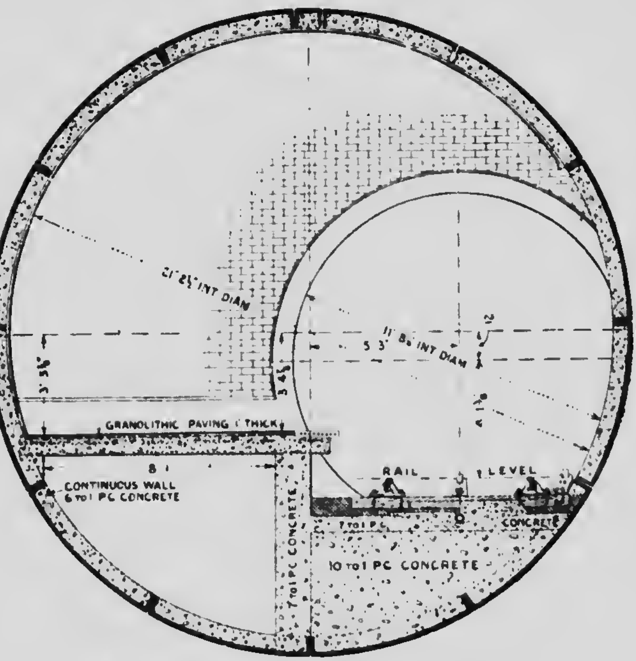


Fig. 1,653.—Cross-section of a Station on the "Bakerloo Tube"

A feature of the planning of the track which is possible under the special conditions of its construction, and is probably unique in railway work, is the system of gradients by means of which a very appreciable economy of working is secured. In all suburban railway work a distinctly important percentage of the energy supplied is wasted owing to the short distance between the stations and the practical necessity for bringing the train to a standstill at each station. At each stop most of the energy used in accelerating the train is wasted in the brakes, and further energy has to be supplied to get up speed again. In the early tube railways, immediately after leaving each station the train descends an incline, which in the Central London line has a 3·3 per cent. gradient; thus gravitation to the extent of 3·3 per cent. of the weight of the train assists the locomotive in producing rapid acceleration. It is calculated that this reduces the demand for power during the period of acceraceltion by about one-half of what would be required on a level line. A vertical profile of the up-line of the Central London Railway is given in Fig. 1,654, the horizontal scale which is marked being, as is usual in such profiles, on a much smaller scale than the vertical scale. The percentage gradient between successive vertical lines is marked as more convenient than the actual heights reckoned from a datum line. The departure gradients referred to above can be seen on the right-hand side of each station level.

On the other hand, when a train is approaching a station it runs up a 1·66 per cent. gradient for a distance of 600 feet, with the result that a 150-ton train stores up potential gravitation energy amounting to 100 H.P. minutes, which is given out in descending the departure gradient to the original running level. As the time of this descent is usually less than a quarter of a minute the power available to assist motors is more than 400 H.P.

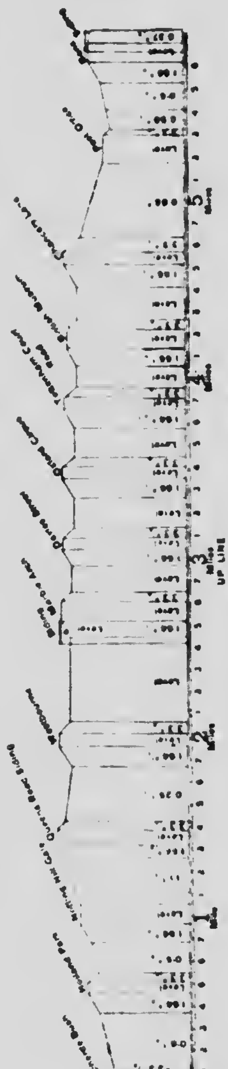


Fig. 1,654.—Central London Railway, Profile of Up Line.

Conductor Rails and Insulators.—After this brief reference to the special features of the London tube railways, we pass to the consideration of the details of the conductors used in "third-rail" and "third- and fourth-rail" systems, the materials being usually the low carbon steel as described in Table XXIV.

The channel section of rail and its supporting insulators have already been referred to and figured in the historical notes (see page 1518). Such sections were used on some of the London tube railways, the Liverpool overhead, and elsewhere. The actual section adopted for the Central London Railway is shown, with the insulating support of the rail, in Fig. 1,655; the drawing is to scale, and the chief dimensions are given; the area of the cross-section is 8¼ square inches. The insulator, which is made of stoneware, is bolted to the cross-sleeper with a ⅞-inch bolt, which is also cemented into the insulator.

Tube Railways.—In the more recently constructed tube railways the "third-rail" system, with the track rails used for a return circuit, has been replaced by the "third- and fourth-rail" system, in which both the + and — conductors are insulated, though, as the latter is electrically connected at

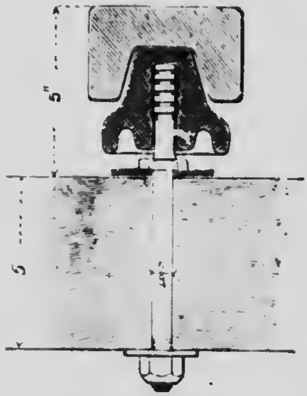


Fig. 1,655.—Rail, Insulation and Support, Central London Railway (1/20)

intervals to the running rails, its insulation resistance is not high. In effect this application of the double-conductor method provides a conductor of higher conductivity in parallel with the track rails, thus reducing the currents in the latter and the leakage currents through the earth, as well as the fall of potential back to the generating or the sub-station.

Sectional drawings of the conductors and their supports, as installed on the "Piccadilly Tube," are given in Figs. 1,656 and 1,657. The first of these (Fig. 1,656) shows the roadbed of the railway as seated on the bottom of the enclosing tube, and carrying both the running and the conductor rails. The drawing is to scale, and some of the principal dimensions are marked on it. In Fig. 1,657 there is given a larger scale drawing of the + conductor and of the outer track rail, that is, the rail remote from the edge of the platforms at the stations. It will be noticed that

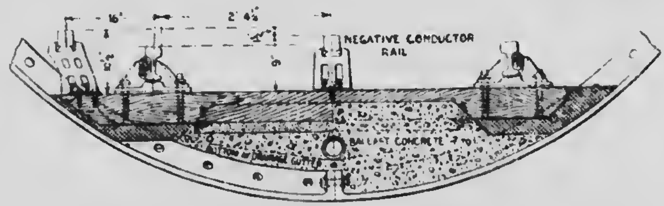


Fig. 1,656.—Road Bed of a Tube Railway showing R[illegible] and Conductor Rails

the gauge of the running rails is the ordinary English railway gauge of 4 feet 8½ ins., that the — conductor is mounted halfway between the running rails with its upper surface 1½ inches higher, and that the + conductor is 16 inches outside the inner flange of the outer running rail with its upper surface 3 inches higher. Details of the concrete, wooden, and other supports are given, and it is interesting to note that the chairs for the running rails are supported on a felt pad to diminish vibration.

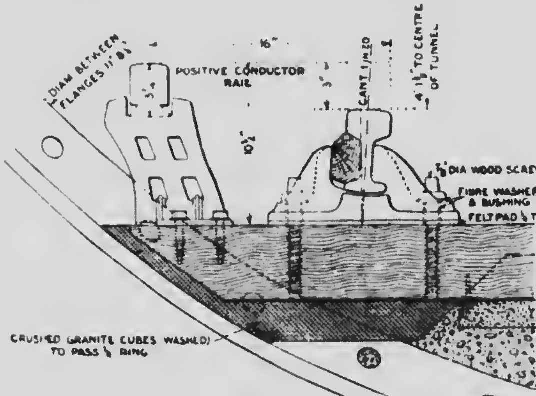


Fig. 1,657.—The Position and Mounting of the + Conductor

The channel-iron pattern of conductor has been replaced, in these more recent railways, by a conductor of rectangular section, 3 1/8 inches high by $2\frac{1}{2}$ inches wide undercut along its lower edges. These conductors are mounted on specially designed but differently shaped insulators, the insulator for the + conductor having a peculiar sloping build to fit the slope of the enclosing tube and to enable the conductor to be placed at the required distance from the running rail to give the necessary space for the fittings of the travelling brush which slides over it. The purpose of the undercutting of the rail is not obvious; it may have been intended to allow the rail to be clamped by wedges or otherwise to the insulators, but no indication of such clamping is given in the drawings.

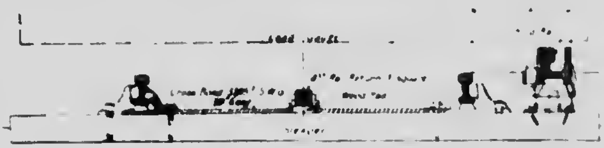


Fig. 1,658. The Positions and Mountings of the Conductor Rails, Lancashire and Yorkshire Railway ([illegible])

*Surface Rail*ways.—In the open, where the confined conditions of tube railways are rel[illegible]urth rail takes a more natural position, as will

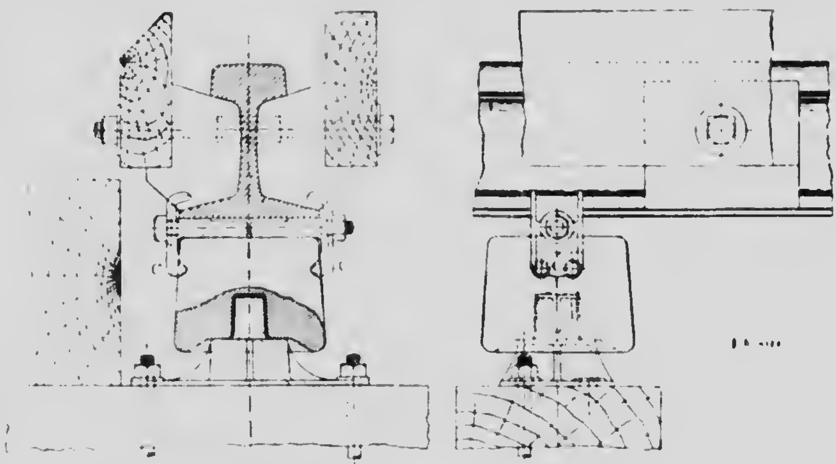


Fig. 1,659. Fig. 1,660.

Conductor Rail and Insulator, Manhattan Elevated Railway.

appear from an inspection of Fig. 1,658, which represents a cross-section of the track and rails of the Lancashire and Yorkshire Railway between Manchester and Bury, which was electrified in 1915. In this case the third, or insulated, rail is some 18 inches outside one of the running rails, and the fourth rail is uninsulated, being laid on the sleepers in the centre of the track and bonded at intervals of 100 yards to the running rails on either side. Except at junctions and cross-overs, the third, or "live" rail, which is at a potential of 1,200 volts, is placed in the six-foot way. Further particulars are given later (*see* page 1594).

It will be noticed in the above illustrations that the inverted channel-iron form of cross-section for the conductor rail has been superseded for open-surface railways, and, as already remarked, for the later London tubes, by other forms considered more suitable for the general plan of working. For ordinary surface railways a favourite form of cross-section is one similar to that adopted for traffic rails, as such sections can be produced with the ordinary rolls available in the rolling mills. An example of some historical interest is given in Fig. 1,659, which is a cross-section, and in Fig. 1,660, which is a side view of the conductor rail used in 1901 on the Manhattan Elevated Railway. The cross-section of the rails was of the shape shown and 9·8 square inches in area, being, as a conductor, equivalent to a copper conductor 1·25 inches in diameter. The rails were rolled in 60-foot lengths and weighed 100 lb. per yard. The insulator was carried on the central pin of a casting bolted to the wooden cross-sleeper, and had a moulded groove in its side to receive the lower projections of the simple clamps, etc., bolted together by a steel bolt lying on the top of the insulator,

Fig. [illegible]. Expansion Joint and Bonds on Conductor Rail.

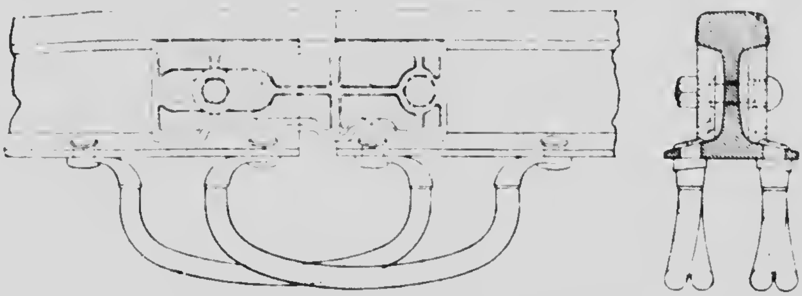


Fig. [illegible]. Expansion Joint and Bonds on Conductor Rail.

and with their upper projections clamping the flange of the rail. With these clamps the rail was free to expand and contract, and was divided up into 300-feet sections consisting of five rails butted up together and anchored at the middle. Expansion was allowed for at the end of each section by a wide expansion joint and special fishplates as shown in Figs.

Fig. [illegible].—End of Conductor Rail at a Break.

1,001 and 1,002, of which the former is from a photograph of the actual joint and the latter consists of drawings to scale of a side elevation and cross-section. The maximum allowance for expansion was 3 inches, and in both figures the heavy copper bonds required to carry the current across the break are conspicuous.

Fig. [illegible].—Expansion Joint with Wooden Guards in Position.

Where the conductor rail or one of the conductor rails is outside the track, provision must be made for continuity of contact at cross-overs and junctions. At such places the outer conductor rail must obviously be interrupted to allow the track rail, which must be mechanically continuous, to follow its destined course. The difficulty is overcome by placing short lengths of conductor rail on the other side of the train and providing contact makers or brushes at both sides, so that contact is never completely interrupted. This renders necessary some arrangement by which the contact shoe can be guided up or down at the ends of the conductor rail when a break is necessary. The arrangement adopted in the early days on the Manhattan Railway is shown in Fig. 1,663, in which R R is the end of a conductor rail at a break. It will be noticed that the end is tapered off so that make or break with the contact shoes may be gradual. In this case there were four contact shoes on each motor coach. Insulators supporting the rail can be seen at I I, and the flexible cables supplying current to the insulated rail are visible on the left.

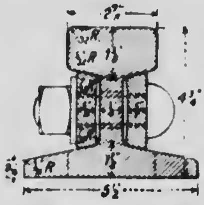


Fig. 1,665.—Section of L. and N.W. Railway Conductor Rail.

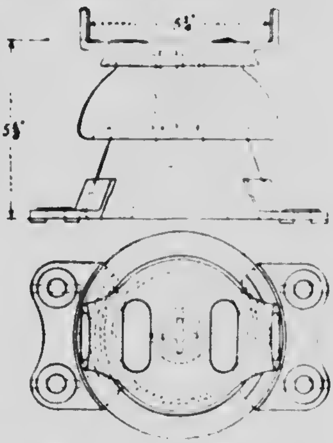


Fig. 1,666.—Details of Ordinary Insulator.

Notwithstanding the enclosed nature of the track, wooden guard strips were provided as shown in Figs. 1,659 and 1,660. These guard strips, which are referred to more fully later on, were intended as a safeguard against accidental shocks to employees, and also to prevent fallen telegraph or telephone wires from earthing the insulated rail; they projected 2 inches above the level of the rail, and were bolted to it as shown. A perspective view of the guarded rail at one of the expansion joints is given in Fig. 1,664.

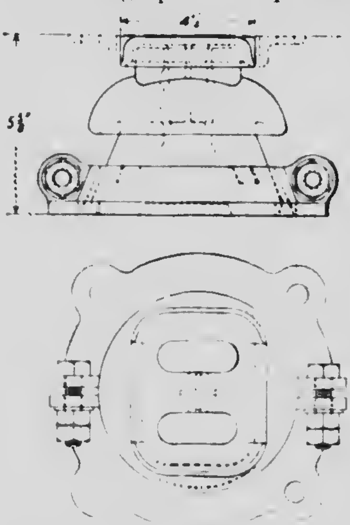


Fig. 1,667.—Details of "Anchor" Insulator.

The conductor rail adopted in the more recent electrification of the London lines of the London and North Western Railway is shown in section, with fully dimensioned details, in Fig. 1,665. The conductor stands 4¾ inches high, and has a working face 2⅞ inches wide. Its composition has been already given in Table XXIV. (page 1523), its specific resistance being about 6·5 times that of copper. The working pressure of the system is about 600 volts, and the positive conductor rail is laid outside the running rails, between which the negative conductor is placed as in the Piccadilly Tube (*see* page 1528) and in the Lancashire and Yorkshire Railway electrification (*see* page 1520). The positive rails are supported by porcelain insulators of the pattern shown in elevation and plan in Fig. 1,666, which raise the inner under surface of the conductor

$5\frac{3}{8}$ inches above the upper surface of the sleeper, to which the insulator is attached by malleable iron clips. The chief details can be made out with the assistance of the dotted lines, the metal cap on which the rail rests has a central pin which drops into a hole in the single-shed insulator, the foot of which is clamped down as shown. To prevent creeping, due to changes of temperature and vibration, "anchor" insulators are used at intervals. One of these is shown in section and elevation in Fig. 1,667. The base-plate clamp is more elaborate than the ordinary clips, and firmly embraces the base of the insulator on which it can be tightened by bolts secured by lock nuts. On these insulators the conductor is more firmly gripped than on the ordinary insulator, the details of the clip used being shown in Fig. 1,668.

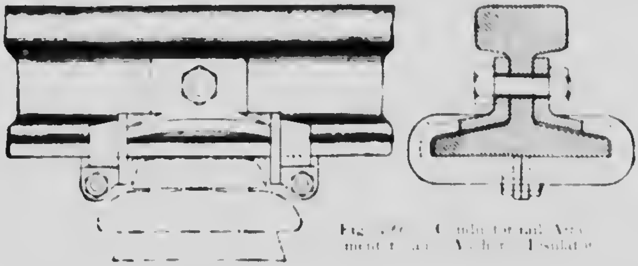


Fig. 1,667.—Conductor-rail Anchorage on Anchor Insulator.

Fig. 1,669.—Sealing Terminal for Connecting Separate Sections of the Conductor Rail.

At crossovers, turnouts, etc., as already explained, the positive conductor has to be laid in sections, often at different sides of the track, and these sections must, of course, be electrically connected, which is usually done by short lengths of what are known as "jumper" cables. In the case of the London and North Western Railway the jumper cables are laid solid in bitumenised fibre troughs, and are fitted with Mr. Cortez Leigh's patent sealing terminal, illustrated in Fig. 1,669. This terminal is designed to form an effective seal to the insulated part of the jumper, and to

Fig. 1,670. Fig. 1,671.
American Types of Insulators for Conductor Rails.

prevent damage to it from mechanical shocks and vibrations on the conductor rail.

Standard types of insulators for carrying flanged conductor rails, similar in some respects to those used by the London and North Western Railway Company, are shown in Figs. 1,670 and 1,671, which illustrate insulators made by Messrs. Anderson & Co., of Boston. They differ from one another in the bases by which they are to rest on the sleepers, the differing forms of these bases being clearly shown. These insulators are of American design and to some extent typical of insulators which are more widely used on the other side of the Atlantic than in this country. The insulating material used, instead of being porcelain or other ceramic substance, is moulded material, the employment of which for overhead work has already been described and illustrated in the preceding chapter on pages 1,304 to 1,307, and in Figs. 1,463 to 1,476. In the insulators shown in Figs. 1,670 and 1,671, this material is the "Aetna" insulating material, used in Fig. 1,471 for overhead work. As illustrating the details of the methods of adapting such insulating material to the requirements of an insulator which is to be used for insulating the "third" or "fourth" conductor rails in electric railway work Figs. 1,672 and 1,673 are sectional views of two other patterns of such insulators manufactured by the Western Electric Company of Chicago, with a special insulating material known as "Electrose." The details of construction can be clearly made out from the drawings. Each insulator is in two parts, (i.) a base which is made of several standard heights to suit different conditions, and (ii.) an insulating and rail-carrying section which

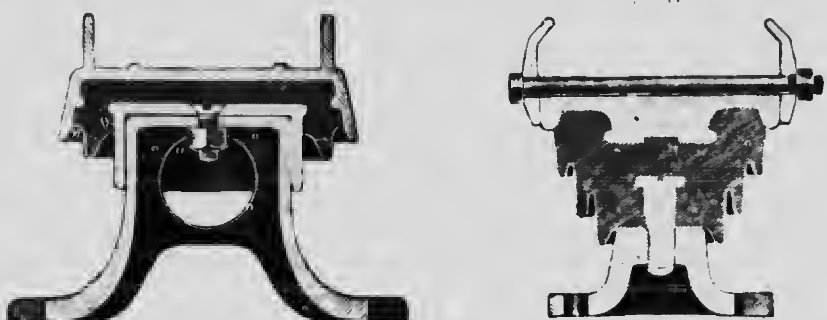


Fig. 1,672. Fig. 1,673.
Third rail American Insulators with Moulded Insulating Material.

can be quickly and securely made fast to the base. The insulator shown in Fig. 1,672 may be regarded as of the double-shed pattern, and that in Fig. 1,673 as a triple-shed insulator (see pages 1110 and 1111).

Most of the immediately preceding figures (1,655 to 1,673) give details of conductor rails and insulators, etc., in which the *top surface* of the rail is utilised for the rubbing contact. But we have given in Fig. 1,658 an example of a third or fourth-rail conductor where the *vertical s*[illegible] rail is so used. In Fig. 1,674 the conductor rail, which has a cross-section similar to that of the running rails in some of our illustrations, is so mounted that contact can be made only with the *under surface*.

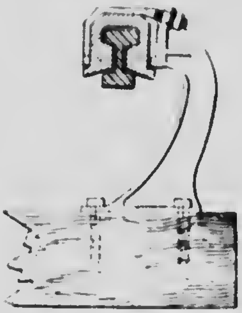


Fig. 1,674.—Conductor Rail with "Under-surface" Contact

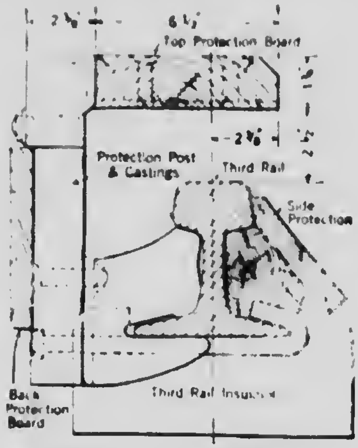


Fig. [illegible].—Protected Third Rail

Besides making it easier to afford protection against accidental contact, a point to which we refer later, the vertical and the under-surface contact systems have the advantage that dirt, frozen snow or sleet cannot so easily accumulate on the working surface as when the upper surface is used. On the other hand, the running collectors or brushes cannot be so simply designed.

Protective Screens.—As explaining at least one of the reasons for adopting other forms of conductor rails, attention may be more definitely directed at this point to the fact, already referred to on page 1532, that, notwithstanding the enclosed nature of the land on which railways are built, it has been deemed expedient to shield the "live" conductor so as to guard against accidental shocks to employees, and other possible accidents and detrimental conditions which may arise from time to time in actual service. An example of such shielding has been already given in Figs. 1,659 and 1,660 (page 1526).

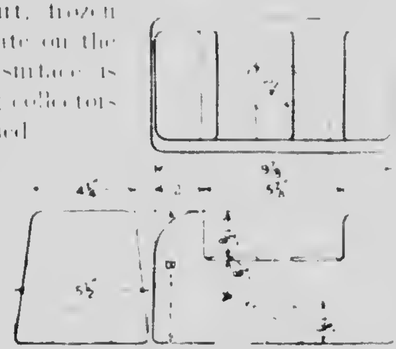


Fig. [illegible]

Details of another example of more recent date are given in Fig. 1,675, which shows, partly in section, the method of protection adopted on a well-known American railway. The castings which [illegible] the protecting boards are clamped to the conductor rail by a hook bolt at convenient positions between the insulators. Dimensioned drawings of the insulators are given in Fig. 1,676, which may be compared with Fig. 1,650 as illustrating more recent American practice. The protection was only used at stations and for 75 feet on either side of level crossings, and the supports were spaced 7 feet apart. The top protection board projected beyond the rail and left a vertical clearance of only $2\frac{1}{2}$ inches for the running collector. A thin vertical board was used for side protection on the outside or side farthest from the track rail, whilst on the inside the side protection was directly attached to the conductor rail as shown. A still more recent and simpler method adopted on the same railway is shown in Fig. 1,677. In this case, there is only a top protection board carried on uninsulated supports.

As we have just pointed out, it is partly to ensure more effective protection that the method of collecting the current from the fixed conductor has, in some cases, been modified, so that instead of utilising the top surface of the conductor for this purpose, notwithstanding its obvious advantages, some other surface, not naturally so fully exposed, is preferred. Thus in some modern systems, as we have shown, the vertical side or even the under surface of the rail is utilised as the rubbing surface, and these systems, as a rule, afford advantages in the design of protective covering not offered when the upper surface of the rail has to be exposed for contact with the running collector.

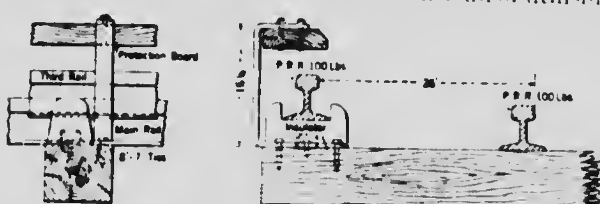


Fig. 1,677.—Later Form of Third-rail Protection.

An example of a side-running contact on a carefully protected live rail is given in Fig. 1,678, which gives dimensioned details of the third rail insulator and protecting wooden strips, and also of the collector, used by the Lancashire and Yorkshire Railway Co., to which reference has already been made on page 1520. The working pressure is 1,200 volts, and the conductor, with its cross-section shaped as shown, is in 60-foot lengths which weigh 85 lb. per yard, giving a cross-sectional area of about 8·35 sq. inches, with a resistance of 6·5 to 7·0 times that of copper. The insulators, made by Doulton & Co., are of white porcelain, $6\frac{1}{4}$ inches high, of the petticoat or umbrella type, with a creepage surface of 8 inches from metal to earth; each insulator is kept in place by three small clips. The guarding material is of jarrah wood, and is held in position by clips *a a a*, secured by chair keys *k*, no screws or nails being used. The rail is kept in place by the projection *p* on the upper part of the insulator, acting in conjunction with the guarding as a key, but there is a wooden packing between the rail and the porcelain inserted to act as a buffer. The insulators are 12 feet apart, and there is a specially designed anchoring insulator every 100 yards. The details of the sliding contact or collector shown in Fig. 1078 are described later (*see* page 1539).

Current Collectors.—The type and design of the current collector and the fitments by which the current is transmitted to the train circuits are obviously as important as details of an electric railway system as they are for electric tramways. Consequently much time and ingenuity has been devoted to their elaboration, and a complete account of the results would require a volume for adequately detailed descriptions. It is, therefore, only possible to refer to the principal considerations involved, and to illustrate them by a few typical examples without attempting to treat the subject exhaustively, notwithstanding the interest attaching to it.

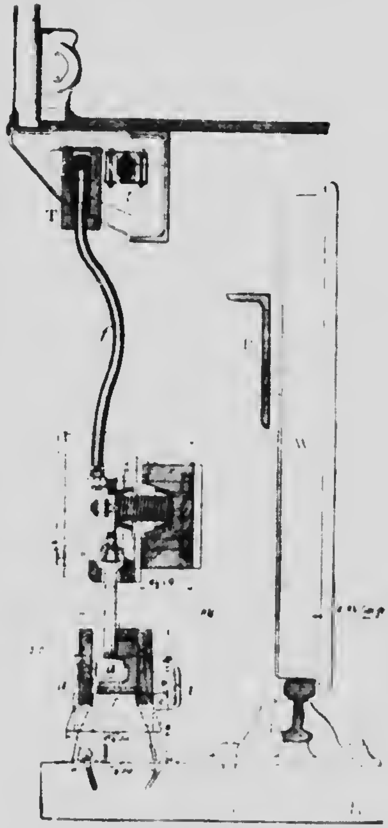


Fig. [illegible]

The main objects are obviously to secure a good electrical sliding or rolling contact by means of apparatus sufficiently substantial and carefully thought out in its details, to ensure that it will stand the most severe conditions of service without undue multiplicity of breakdowns and with economy in the total cost of upkeep. The special conditions which have to be satisfied at junctions and cross-overs must be carefully kept in view, and to satisfy these it has frequently happened that the whole design not only of the collector but of the arrangement and position of the fixed conductor rail has had to be modified.

Rolling contacts, which are so largely used for overhead work, are not, so far as the author is aware, used on any important systems for third or fourth-rail collectors, the actual moving contacts being metal brushes, slippers or plates. Whatever form of contact is used, it is essential that there should be some flexibility in the travelling collector or its mounting so as to allow for inequalities of the position of the fixed conductor rail and

See [illegible] 1682 [illegible] 68 [illegible] *Railway* [illegible] for the movements of the supports of the collector due to the vibrations, oscillations or other movements of the train especially at high speeds.

In the early City and South London Railway, sliders moving over the conductor of inverted channel iron were employed, as can be seen by reference to Fig. 1,642. A better view of an early pattern of collector shoe is given in Fig. 1,647, which shows in full detail the shoe used on the Liverpool Overhead Railway when first opened.

Fig. 1,679.—Contact Shoe for Third Rail in Position for Collecting Current.

A later form of contact shoe carried at the side of the car is shown in Fig. 1,679. It was used on the Albany and Hudson Electric Railway, the coaches on which were partly railway and partly tramway coaches. At the two ends of the line these coaches ran as tramcars, taking current from the overhead trolley lines of the two cities between which they acted as a link. Outside the cities for 37 miles the track ran through the enclosed land of the railway company, and the current was picked up from a third rail along which the steel shoe shown in the figure slid. This shoe is a steel plate carried by two links, and the flexible conductor by which the current is carried from the contact plate to the fixed car circuits is clearly depicted. The unguarded third rail was, of course, not continued into the streets of the city, and to protect the shoe from injury when the trolley was to be used the hinged bar upon which the shoe was mounted was raised by hand and secured in its place by the pin *b*, as shown in Fig. 1,680.

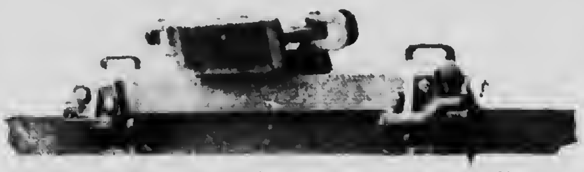


Fig. 1,680.—Contact Shoe Raised and Secured when not in Use.

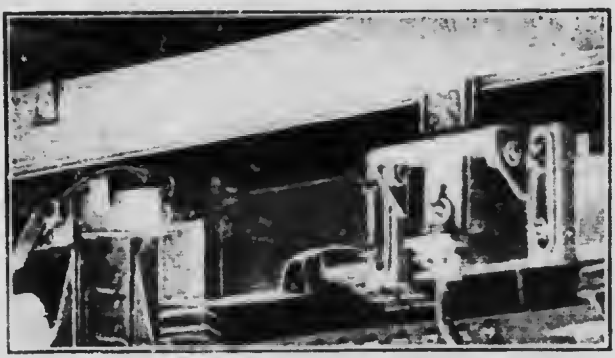
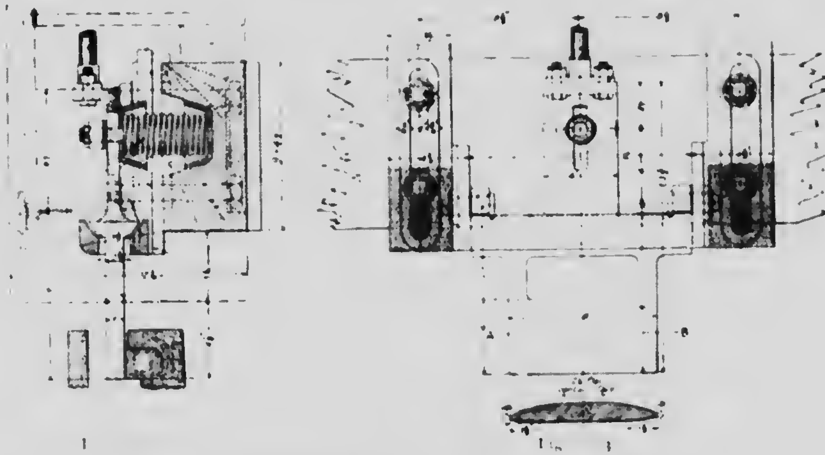


Fig. 1,678.—Side-running Current Collector Mounted on Tram

The side-running current collector used by the Lancashire and Yorkshire Railway on its Manchester and Bury section is shown in Fig. 1,681 in position as mounted on the bogie of the motor carriage. A cross-section of this collector has already been given in Fig. 1,678, but the more important parts of this cross-section are shown on a larger scale in Fig. 1,682, together with a side view in Fig. 1,683. The principal dimensions are inserted. The contact piece or shoe is swung on a hinge and is pressed flexibly against the conductor rail c by the spring s. For other chief details, the figures are self-explanatory. The car cable is carried in a jarrah trough t (Fig. 1,678), and the contact shoe is joined to it by the flexible cable *f*. It may be of interest to note here that the low voltage cable for the controller circuits are carried in the steel trough h.



[illegible]

The relative position of the running wheel w and the sole bar B of the bogie are also shown.

IV. OVERHEAD SYSTEMS

In the last chapter (pp. [illegible]) there is a very full description of the methods adopted for suspending an overhead conductor from suitable supports for supplying electric energy to the motors of vehicles running upon ordinary roads. These methods are of course available for railway work, so far as the main supports are concerned, [illegible] railway work. For obvious reasons, however, side poles with [illegible] conductor are more widely used for such work than the bracket [illegible] commonly employed for work on public roads.

Mention was made on page 1,387 and again on page [illegible] that supporting brackets or span wires having been provided there are two methods of hanging the conductors from these supports, [illegible] and by the *catenary* method. The former [illegible] method used for street and road traction was then fully described.

and the latter being more largely used in railway traction was reserved for treatment in the present chapter.

Catenary Suspension.—The chief feature of this method is that the main supports of the types described in the preceding chapter carry directly a flexible cable or cables generally consisting of stranded steel wire, which is not used as a conductor for the electric current, but from which the copper or other conductor is suspended by a series of clips much more closely spaced than the main supports. The flexible cable is the "catenary," which is the name of the mathematical curve in which a perfectly flexible heavy wire or cord hangs freely when supported at its two ends. The catenary is usually, but not necessarily, carefully insulated, for it is easier to insulate it than to use insulating suspenders between it and the conductor, which must be insulated. Though, therefore, not reckoned as part of the transmission circuit, the catenary or "messenger," as it is often called, does carry a portion of the supply current, and so reduces the effective resistance of the circuit.

Fig. 1,684. Double Catenary Suspension, London, Brighton and South Coast Railway, London.

An early method of catenary suspension which has been widely used is shown in Fig. 1,684. The example is taken from the metropolitan section of the London, Brighton and South Coast Railway between London Bridge and Victoria, which was electrified in 1906-1909. In this case there are, for each conductor, two suspending cables forming what is known as a double catenary. These cables are carried on porcelain insulators erected on the top member of trellis girders supported across the railway tracks by side posts erected on the side of the running tracks. The form of insulator adopted was the result of carefully conducted practical tests extending over nearly twelve months. From the two catenary cables the conductor is suspended by clips at 10-feet intervals, these clips gripping two grooves in the conductor, which is otherwise of circular cross-section.

The construction shown in Fig. 1,684 is that adopted for the straightforward case of a double line of railway on an open viaduct; but where the conditions are not quite so simple—as, for instance, in tunnels, under bridges, and at junctions—it has to be considerably modified. This will be evident from an inspection of Figs. 1,685 and 1,686. In Fig. 1,685 the train is shown entering a short double-line tunnel at Denmark Hill. It is obvious that the supports already described (one of which is seen in the

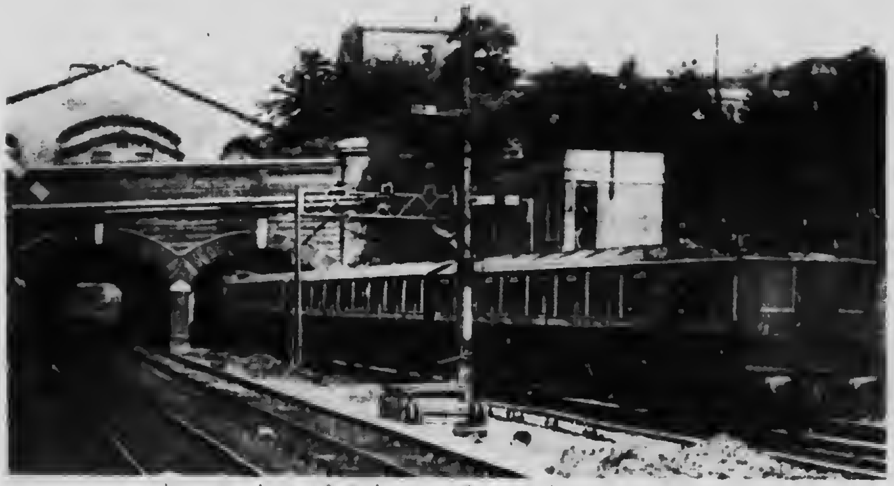


Fig. 1,685.—Electric Train Entering a Tunnel at Denmark Hill

picture) cannot be used in this tunnel, in which the clearance space above the top of the train is very much reduced. The conductors have therefore to be supported from stout insulators fixed to the roof of the tunnel. An example of such a suspension taken from another system is given later (see Figs. 1,706 to 1,708).

Another special case is illustrated in Fig. 1,686, where the suspended conductors are shown as they pass a signal station at the entrance to the London Bridge terminus. In addition to having to pass under the supports for the signals, the crossing and curving of the tracks have to be taken into account; and on the extreme right provision has had to be made for a cross-over on to another line. Brackets, cantilevers, and other devices are used; the second lattice girder should be noted as it shows, with its extended cantilever on the right, the simpler carrying forward of the lines after the curves and junction points have been passed.

The electrified section of the railway just described was, as already stated, opened for service in [illegible]. As showing the similarity of English and American practice at that epoch, Fig. 1,087, taken from a paper read by Mr. Westinghouse before the *Institution of Mechanical Engineers* in London in 1910, is a view on the New York, New Haven and Hartford Railway, showing the overhead wire supported by double catenary steel cables from

[illegible]

lattice steel bridges very similar to those shown in Fig. [illegible] on the London line. This view is further of interest as showing clearly how a transverse stay was used between the bridges to pull the supporting cables into their required positions above the tracks when going round curves. When the curves are of short radius the necessity for keeping the conductor wire in its proper position may obviously require shorter spans between the main supports. Where, in addition, there are cross-over points as well as curves, much more complicated constructions have to be designed and erected.

A simplification of the method of supporting the conductor adopted widely in subsequent work consists in using only one supporting catenary

cable in place of two. This method is shown in its simplest form in Fig. 1,688, taken from a paper read by Mr. W. B. Potter at the meeting just referred to. This figure shows standard American practice at that time. The "single catenary" for each road of a double-track railway is supported by insulators carried on simple brackets fixed on wooden poles at the side of each track. The view is taken from an interurban line running between Baltimore and Annapolis in Maryland. The conductor is suspended from the catenary by the usual hangers, to which further reference is made later. On the two posts in the foreground insulated anchoring arms are shown, the object being to steady the freely suspended conductor. The working voltage on the conductor was, in this case, 6,600 volts.

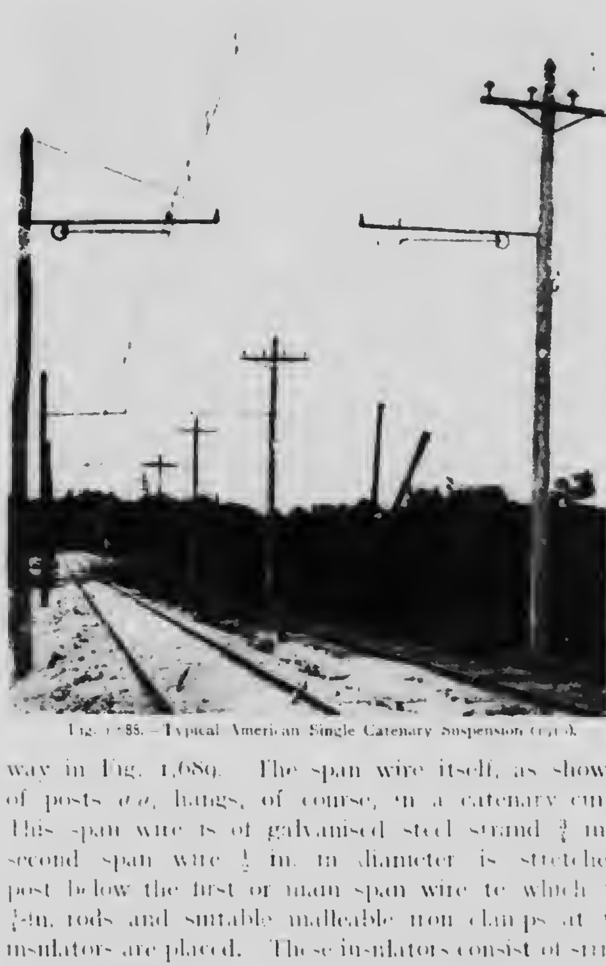


Fig. 1,688.—Typical American Single Catenary Suspension (G.E.).

The span-wire or cross catenary method (see page 1387) of supporting the catenary cable or "messenger" is often employed. This method is shown in its simplest form as erected on a four-track section of the Pennsylvania Railway in Fig. 1,689. The span wire itself, as shown at the second pair of posts *a a*, hangs, of course, in a catenary curve across the tracks. This span wire is of galvanised steel strand $\frac{3}{4}$ in. in diameter, and a second span wire $\frac{1}{2}$ in. in diameter is stretched taut between the post below the first or main span wire to which it is tied by vertical $\frac{3}{4}$-in. rods and suitable malleable iron clamps at the points where the insulators are placed. These insulators consist of strings of the glass insulators of the suspension type already fully described (see pages 1130 *et seq.*). The porcelain discs of the insulators are 8 inches in diameter, and the flash-over value of the three is many times the line voltage. On straight runs the supporting tubular iron posts are 300 feet apart, but are closer on curves. The messenger wire is a ⅝-inch, seven-strand double galvanised steel cable, and the standard sag is 5 feet at the middle of a 300-foot span. The hangers are 15 feet apart and support two wires at their lower ends. The upper one of these, called the "auxiliary messenger," is of copper, circular in section and 0.325 inch in diameter. Its object is to give the requisite current carrying capacity to the system. The lower contact or trolley wire, in a vertical plane with the upper one, is a phono-electric grooved conductor 0.450 inch in diameter made of an alloy of higher specific resistance. The standard height of the lowest conductor is 22 feet above the rail.

Fig. 1,089.—Single Catenary with Span-wire Suspension.

In single catenary construction special devices must also be used on curves to keep the conductor approximately in its proper position over the track. One method of doing this is shown in Fig. 1,090, which shows a part of a 2,400-volt D. C. overhead line at a curve. It

Fig. 1,090.—Single Catenary Construction on a Curve.

will be noticed that an insulated arm is carried on an extension of the bracket and pulls the conductor away from the post which is on the inside of the curve. The posts are spaced so that this device is sufficient for the purpose.

A case of a much sharper curve is shown in Fig 1,691, which is a view on the Pennsylvania Railway. The method of supporting the messenger cables is the span-wire method, already described, with the messengers carried by suspension insulators. The tops of the rings of insulators supported by the span wire are tied together as already explained by an uninsulated transverse wire attached to the same posts and stretched immediately below the span wire, and kept taut by a turnbuckle. In their turn the contact wires are tied together by another but insulated horizontal wire stretched between the posts at a still lower level, and also kept taut by a turnbuckle. It will be noticed that the contact wires are pulled a long way from their usual positions immediately below their supporting messenger wires.

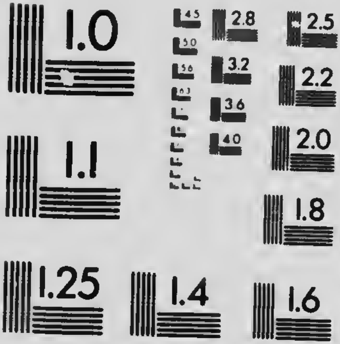
Fig. 1,691.—Single Catenary (Span-wire) Construction on a Sharp Curve

Still more complicated cases arise at junctions or turn-outs where there are necessarily curves and two contact wires coming together. A somewhat complicated case in which there are no fewer than nine straight tracks with cross-overs at different points is shown in Fig. 1,692, which is another view taken on the Pennsylvania Railway. It is made still more interesting from the fact that it illustrates a change-over from the span-wire to the bridge-girder method of supporting the numerous messenger wires. In the foreground *s s s* is a span wire hung from trellis-work steel towers at the sides of the viaduct, but not shown in the illustration; the lowest point of the span wire is at *c*, where it supports the messenger for the centre track. Attention should be directed to the methods used for keeping the messenger and contact wires in their proper positions, and especially to the horizontal steadying wire *a a a* which runs across below the span

Fig. [illegible]. Catenary Suspension on Junctions and Straight through Lines. Span-wire and Bridge-girder Support.

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



APPLIED IMAGE Inc
1653 East Main Street
Rochester, New York 14609 USA
(716) 482 - 0300 - Phone
(716) 288 - 5989 - Fax

wire on the upper or earth end of the insulators. Stiff rectangular frames with the corners cross-connected and other devices can also be detected at the cross-overs.

A simpler instance, where there are two lines on the right hand running into a straight-through line on the left, is given in Fig. 1,693. Some of the devices for keeping both the supporting cable and the contact wires in their required positions relatively to the tracks can be clearly made out, and need no further description.

The systems from which the above illustrations have been taken are all single-phase alternating or continuous-current systems in which the rails and the earth complete the circuit to the generator or sub-station, and which therefore require only one overhead insulated conductor. Such systems are usually employed in this country and in America. In Italy, Switzerland, and elsewhere in Europe, three-phase alternating-current systems have been successfully developed, which, so far as the writer is aware, all use overhead wires for their insulated conductors. In these cases, as the three phase lines must be insulated from one another, only one of them can be uninsulated, and therefore *two* overhead lines each insulated from the earth and from the other must be erected. There must also be a collector which will carry two of the phases by conductors insulated from one another into the moving vehicle or tram.

Fig. 1,693.—Curves and Junctions in Catenary (Bracket) Construction.

These conditions complicate the mechanical and electrical devices both in the overhead lines and in the collectors, and the fact that they have been successfully satisfied in practical working is a praiseworthy engineering feat.

Some of the details for one of the solutions for the overhead conductors are very clearly given in Fig. 1,694, which is taken from Mr. Westinghouse's paper, already referred to, and is a view on the Lecco-Calolzio line in Italy.

The supports for the messengers are long brackets projecting from lattice posts at the side of the track. The supporting part of the arm of one of these brackets is shown at the top of the figure, where also the main details of the insulating supports of the messenger cables can be seen. A horizontal rod is supported by insulating sleeves from two hangers attached to the bracket arm which is, of course, uninsulated. In the straight through case on the left the supports for the messengers are carried over the rod by insulating sleeves, and projecting downwards from these there are short vertical arms carrying articulated light links for steadying the conductor wires.

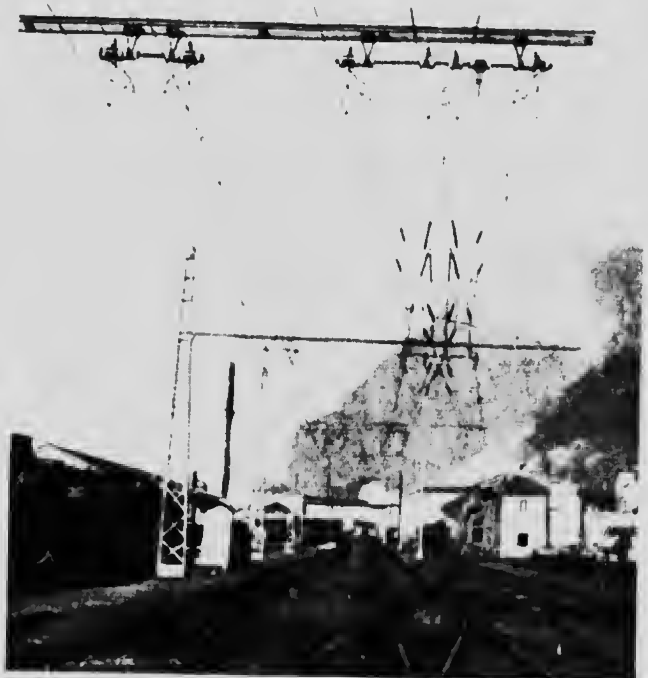


Fig. 1064.—Three-phase Catenary Suspension [illegible]

The figure is further interesting as it shows on the right the modifications for a cross-over at an acute angle, and a junction with the supports for four messenger cables and their conductors. The two outer cables are supported as in the straight-through case, but the two inner ones are on sleeves which have no lower projections, the place of these being taken by a much stronger vertical arm from which links grip the two messenger cables directly, and the two conductors through articulated links, these conductors being tied together a little farther on. The middle conductor for a short distance on either side of the bracket have section insulators inserted as have also the outer conductors; the middle conductors and probably but not necessarily the outer ones are dead for the short distance to avoid the phases being short circuited.

The view of the overhead construction for a three-phase system given in Fig. 1065 will perhaps be of more general interest, as it depicts a short length at the entrance to the well-known Simplon tunnel in the Swiss

Alps. It is also of interest because of the commendable simplicity of the details of construction designed by Messrs. Brown, Boveri & Co., of the Oerlikon works, who erected the line. In fact, it is so simple and clear that no further description is necessary except to call attention [illegible] the insulation of the span wire [illegible] addition to the insulation fr[illegible] another of the conductors wh[illegible]h are to carry the currents [illegible] the phases. A view of the line inside the tunnel, through w[illegible]ly a single line runs, is given later (*see* p. 1558).

[illegible] Conductor and Contact Wire.—The choice of the material for the overhead conductor in a catenary system of railway working offers more difficulty than in the case of the trolley wire for road traffic, since the conditions of service are more severe. Not only is rolling contact replaced by sliding contact, for reasons which we shall explain presently, but the speeds attained are greater than in the case of road traffic. The mechanical properties of the conductor as regards hardness and power to resist attrition are therefore relatively more important, though high electric conductivity is also essential.

Fig. [illegible]. Three-phase Overhead Construction in the Alps (the Simplon Tunnel).

The claims of high electric conductivity being considered paramount, hard-drawn copper wire was first used, but was found to wear away too rapidly. Copper alloys of much better wearing properties but of lower conductivity have therefore been extensively employed, and composite wires made of copper and steel have also been tried, the copper being the conducting core, and the steel a hard protecting sheath outside it. So-called "phono-electric" wire which, with similar alloys, is widely used has a conductivity about 40 per cent. of that of pure copper, but a much higher tensile strength. In comparing hard-drawn copper wire with these alloys it must be remembered that in wires of the sizes used for overhead lines the strength of hard-drawn copper is only skin deep, the cores of the wires being practically of soft copper. If therefore the skin layer is worn away by abrasion the whole wire may give way under the mechanical forces to which it is subjected.

In order to combine the advantages of the high conductivity of pure copper with the better mechanical properties of other material, the following method was devised by Mr. E. H. McHenry, and is now very widely used. A copper wire was suspended from the messenger in the ordinary way, and from it a steel contact wire of the same section was suspended by clips placed midway between the hangers. These clips were used to keep the wires about 1¾ inches apart, centre to centre. The lower steel wire acted as the contact wire, and took all the wear, whereas the copper wire above it, usually referred to as the "*secondary messenger*," played the chief part in the conduction of the current. Difficulties occurred in practice in carrying out the idea, and the design and spacing of the hangers have been varied. Steel being liable to rust should, in damp climates, only be used where the traffic is sufficient to keep the wire clean; in many cases its place is taken by phosphor bronze or "phono-electric" wire which is not liable to such corrosion.

The Hangers.—Many varieties of hangers or suspenders for use in catenary systems have been designed and tried in practice, and it is possible that the best type has not yet been evolved. Some of the existing types take too long to install, and therefore unduly increase the cost of erection. Another serious fault with some patterns is that they shake loose in service.

Details of some hangers in actual use can be seen in the figures given elsewhere. In the double catenary system, illustrated in Fig. 1,687, the hangers, about 10 feet apart, are made of pipe in the form of inverted equilateral triangles, the two upper corners of which are attached to the two messenger cables, the conductor wire being gripped at the lower angle. The details of the hanger used in the Montreal tunnel can be seen on Fig. 1,707. In most of the figures, however, the scale is too small to show details, and therefore we give here a few more examples.

Three types of single conductor hangers for suspending the conductor from a single messenger are shown in Figs. 1,696 to 1,698. In Fig. 1,696 a broad metal strap in the form of a loop slides on the messenger, and its two lower ends placed one on either side of a pinching piece can be bolted together; as the bolt is tightened up the jaws of the pinching piece grip the conductor wire. The ends of the strap fit into grooves in the sides of the pinching piece, giving a neat appearance to the hanger when in position. This hanger is made by the Ohio Brass Company and is a standard type.

A later type made by the same company is shown in Fig. 1,697. In this type the strap loop of Fig. 1,696 is replaced by a loop of solid rod or circular section, the lower ends of which are flattened out and pierced; by means of a bolt and nuts and washers, two clamping pieces shaped as shown, can be hung on the loop and made to grip the wire.

The third example, Fig. 1,668, is a more recent standard type made by the General Electric Company, of Schenectady. It consists of a loop of round steel, and of a clamp made of a single steel punching. The ends of the loop are splayed out and fit into depressions in the punching, the jaws of which are then made to grip the conductor by means of the clamping bolt. This hanger is said to be capable of supporting a weight of 2,000 lb., or nearly a ton, and to be exceptionally light. In it and the preceding pattern the round section of the loop reduces the possibility of wear on the messenger cable and offers a minimum of resistance to the wind. The surfaces of the hanger are all sherardised so as to resist the corroding influence of the atmosphere.

Fig. 1,666.

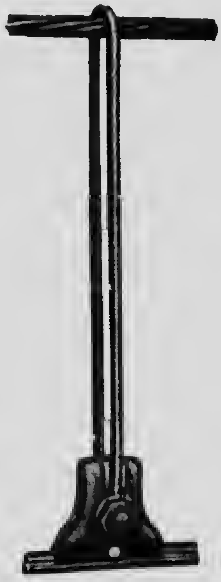


Fig. 1,667.

Fig. 1,668.

Three Catenary Hangers.

The construction of the hangers is necessarily more complicated when a "secondary messenger," in addition to the contact wire, has to be supported by the hanger. A pattern used in a recent extension on the suburban railway system of Philadelphia is shown in Figs. 1,669 and 1,700, which depict long and short hangers respectively. In each the body of the hanger consists of an appropriate length of strap steel which in the longer hangers is given a half twist to minimise the swaying effect of wind blowing across the track. The half-twist is clearly shown in Fig. 1,669, but the strap in Fig. 1,700, being much too short for the device to be used, is not twisted. The top of the strap is clamped to the ½-inch, seven-strand messenger by a steel strap which passes over the messenger, and grips it tightly when the whole is bolted together. In this respect it differs from many other types of hanger which are purposely designed to hang loosely on the messenger wire.

At the lower end of the strap a bronze clamp is used to grip the secondary messenger as shown. The secondary messenger is of copper with a grooved section of No. 00 gauge, and from it is suspended the phono-electric contact wire of No. 000 gauge, also by bronze clamps.

Fig. [illegible] Fig. [illegible]
Long and Short Hangers for Secondary Messenger and Contact W[illegible]

Hangers of very different design supplied by the Westinghouse Company and used in suburban New York are shown in Figs. 1,701 and 1,702. One of these, Fig. 1,701, is for use on curves, and the other, Fig. 1,702, on straight lines. In both a hook of special shape is slipped over the messenger line which is a $\frac{7}{16}$ inch stranded steel cable. The lower part of the hook carries a threaded sleeve into which the end of the hanger rod is screwed to hold a keeper against the cable in the opening of the hook. The rods are of $\frac{1}{2}$-inch round steel not galvanised, and of varying lengths, according to their positions on the catenary curve.

In the straight line pattern, Fig. 1,702, the lower end of the rod is screwed into a cast metal clamp *a a* which supports only the No. 00 copper secondary messenger, which it is made to grip firmly by a $\frac{1}{2}$ inch carriage bolt. A No. 000 grooved copper alloy contact wire is separately supported $1\frac{1}{4}$ inches below the copper messenger wire by clamps *b b*, shaped as shown, and placed between but not at the hangers. The hangers are 30 feet apart, and there are two bolted clamps between successive hangers.

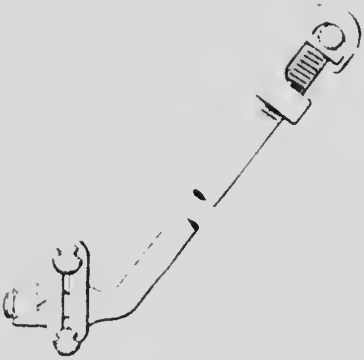


Fig. [illegible] Fig. [illegible]

Hangers for Curves and for Straight Ra[illegible]

The hangers employed on curves, Fig. 1,701, are placed only 15 feet apart, but the lower end of the rod of the hanger is bolted, not screwed, into a cast metal clamp *c c*, which grips both the secondary messenger and the contact wire. No intermediate clamps, similar to *b b*, Fig. 1,702, are used on curves.

Lary. Catenary Support.—As already indicated, the extension of electric traction from tramway to railway conditions introduced new factors into the problems to be solved, and also altered the relative values of importance of some of the older factors. For instance, in overhead construction the suspension of the trolley wire from supports which in a straight run might be anything from 80 to 120 feet apart led, on account of the sag of the wire, to its height above the track being considerably greater at the supports than in the centre of the dip between the supports. For slow running tramcars this did not so much matter, as the pole and trolley wheel had time to respond to these differences of level. Even with tramcar work, however, as speeds increased trouble was experienced through the sluggishness of the response, and the problem of collecting the current at high speeds became more and more serious. What sometimes happened was that the trolley wheel left the wire, thus breaking the circuit and giving rise to a destructive flash detrimental both to the wheel and the wire. But the wheel, having left the wire, might or might not come back on to it in its swing. If, fortunately, the wheel picked up the wire its return at running speed would usually mean a more or less violent hammer blow which, if oft repeated, soon affected the cost of maintenance. If the wheel did not return to the wire the trouble was obviously immediate and serious. The hammer blows, beside their direct effect, tended to pound kinks into the wire, especially in warm weather when the wire was hanging at its slackest and the differences of level were greatest.

An obvious remedy was, if possible, to provide more frequent supports so as to improve the vertical alignment of the conductor. Questions of cost, however, ruled out the reduction of the span between main supports to anything like the extent necessary to get rid of the chief difficulties. Hence the suggestion that the conductor should be supported at short intervals say of 10 to 15 feet, from a steel or other cable, which should itself hang from the main supports, and from which by the use of hangers of different lengths, sufficiently numerous and carefully adjusted, the conductor would be supported in an almost level position at least for certain ranges of temperature. Another solution which was tried, but has been abandoned, was to mount the conductor at the side of the track, the current to be picked up by a vertical bow projecting sideways from the train, and of sufficient length to be in touch with the conductor at all levels.

Incidentally the more numerous supports prevented the wire from falling to the ground if it should be broken, a consideration which became of more and more importance as the voltage used was increased from the 500 or 600 volts of C.C. working to much higher voltages whether C.C. or A.C., for as we state elsewhere, there are overhead systems in which current at 11,000 volts is collected by the moving vehicle.

Special Problems.—A number of interesting problems, both electrical and mechanical, arise in connection with the design and erection of lines using the catenary method of suspension, but considerations of space do not allow us to deal with these problems as fully as we wish. Some of the principal ones only are indicated in what follows, and the illustrations show some of the methods adopted in solving them.

One of the main problems is, for reasons already partly given, to suspend the conductor or "contact wire" so that it shall be fairly level and not "sag" in deep curves in the spans between the supporting brackets or poles in the manner in which the ordinary trolley wire sags. This, as we have seen above, is accomplished by having numerous supports, say at 15-foot distances, for the contact wire, the sag of the long span, of say from 90 to 150 feet, being handed over to the supporting catenary or "messenger" cable. It is a matter of common mechanical knowledge that no material exists which would hold together without breaking if a wire made from it were pulled even approximately level on a 150-foot span. By using long hangers near the poles and short ones in the middle of the span, the sag of the messenger wire is approximately corrected, and the contact wire lies fairly level. Some of the illustrations al[...] or which follow show this variation of the length of the hange[rs ...]ly. The diagram in Fig. 1,703 of the two wires for a 90-foot [span giv]es some actual lenghts of hangers varying from $1\frac{3}{4}$ inches near the points of support to 6 inches in the middle of the span. The sag of the messenger is often, in practice, greater than is there indicated. In this instance, for reasons we need not dwell upon here, there are two contact wires supported by the same messenger, the hangers being 15 feet apart on each wire with the points of attachment to the messenger staggered. The case illustrated occurs in a terminus in Montreal.

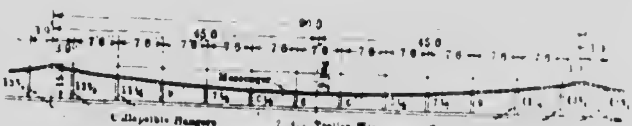


FIG. 1,703.—Diagram showing the Dip of the Catenary Messenger Cable.

Another purely mechanical and important problem is the keeping of the catenary or messenger wire sufficiently taut for (a) its sag not to become excessive when at the highest summer temperature, and (b) the strain on it not to become excessive at the lowest winter temperature. The problem is not so simple as the corresponding problem in the erection of telegraph or telephone wires, because of the heavier cable and the greater weights to be carried, or even as the much more nearly analogous case of the overhead trolley wire in tramway work. There is obviously the complication of the "load" being suspended at specific points, and therefore not being continuously distributed, as when it consists only of the weight of the catenary wire itself. Some special method of anchoring the messenger wire must obviously be employed, but in this connection we can only refer to the solution shown in Fig. 1,704, which is a view of a standard anchor and signal bridge on the Pennsylvania Railway system, other details of which have already been given. These signal bridges are situated about half a mile apart, but only every other one is used as an anchor bridge; that is, in a straight run, about every seventeenth span. At these anchor bridges the messenger is socketed and dead-ended, it is insulated from the bridge by two or more sets of three-unit suspension insulators of the same pattern as those used for the suspension of the messenger from the span wires (see Fig. 1,680). Booster transformers are mounted on the bridge, which forms the end of an electrical section; the "jumper" by which the current is conveyed to the auxiliary messengers on either side of the break can be readily made out. The track on the near side of the bridge is curved, a fact which should be borne in mind in attempting to follow the course of the overhead wires on that side.

Fig. 1,6[illegible].—Anchoring Bridge for Catenary Suspension on the Pennsylvania Railway ([illegible]).

The question of *sectionalising* the catenary system is electrically important, here as elsewhere. The anchor bridges, just illustrated, afford opportunities of doing this. On straight runs this sectionalising is often of the "air-break" type; the ends of the two contact wires overlap one another for a short distance and are spread apart with a transverse interval of a few inches between them. Each is eventually raised and made fast to an insulator past the point where the last contact will be made by the pantograph

Fig. 1,6[illegible].—Catenary passing under a Bridge.

collector. Thus the latter is for a short time in contact with both wires, and is in good contact with the new section before breaking contact with the old. In this way sparking is avoided, and the sections are left with an air break between them when the collector has passed.

Quite another series of problems is met with when the railway line passes under an ordinary road where the difference of level is usually not sufficient to allow of the free suspension of the catenary equipment. This problem has been mentioned on page 1541 where a similar case was illustrated. One method of solution would be to dead end the catenary on each side of the road and carry the conductor under the road by an entirely different system. This would usually be expensive and unsatisfactory if the bridges were numerous.

Fig. 1,766.—Later Method of Supporting Catenary passing under a Bridge.

One of the methods adopted on the Pennsylvania Railway is shown in Fig. 1,765. Two post-type insulators with 8-inch petticoats are attached to the overhead structure by some convenient grip, and support a transverse bar above the track. This bar is therefore insulated and the messenger cable can be supported from it by any convenient mechanical device. In the figure the conductor wire attached to the messenger by the usual hanger is drawn so far to the right by a short bracket supported by the insulated cross-bar that it is almost on a level with the messenger, thus securing greater head room under a low bridge.

Fig. 1,765.—Catenary Support in Montreal Tunnel.

A more recent and more compact method used by the same railway is shown in Fig. 1,766. In this case the messenger is supported directly by

172

F[illegible] View in the Montreal Tunnel

a 14-inch insulator attached to the overhead structure, and having two 12½-in[illegible] and two 13-inch petticoats. The insulator also supports directly as shown the bracket arm which draws the conductor wires nearly up to the level of the messenger so as to give the required vertical clearance.

In the Montreal tunnel of the Canadian Northern Railway, where there is a greater headway, a different method of suspending the messenger is adopted. This is shown in Fig. 1,707, and consists of a cross-bar of channel iron shaped as shown, and supported on insulators resting on bars supported from the roof of the tunnel. The cross-bar carries a double-shed insulator which supports the cable. One of the short hangers by which the conductor is supported is shown, and its details should be noted and compared with those of the hangers illustrated above. The insulator is shown in position in the tunnel in Fig. 1,708, which is a view of a curve in the tunnel; the stays for adjusting the alignment of the messenger and the conductor are also shown.

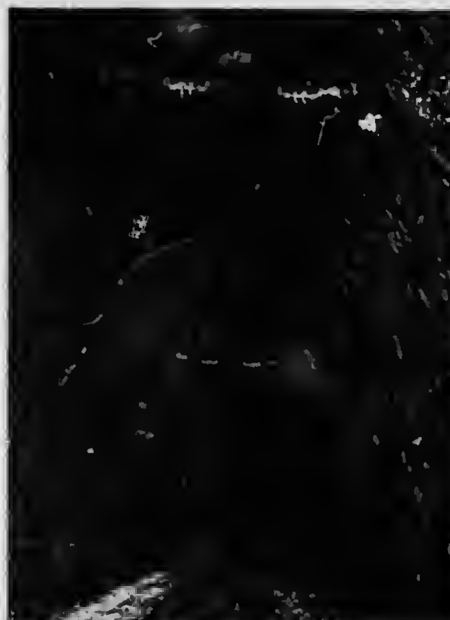


Fig. 1,7[illegible].—Three-phase Conductors in the Simplon Tu[illegible]

As promised above (page 1550) we give in Fig. 1,709 a view of the interior of the Simplon tunnel showing some of the details of erection of the two insulated conductors of the three-phase system used for working the traffic. The method is practically identical with that used in the open (see Fig. 1,695), the chief differences being that the span wire is much shorter, and is, of course, supported directly by bolts with their ends imbedded [illegible] in the roof of the tunnel. It is of interest to note that the [illegible] feeder lines are carried on insulators along the side of the [illegible]

Overhead Collectors for Railway Working. [illegible] with the problems connected with the suspension of the overhead conductor there is another series of problems connected with the design and construction of the collectors which are to pick up the current from the conductors and convey it to the control apparatus and motors on the moving train. These problems are directly influenced by the higher speeds which have to be provided for in railway traffic as compared with tramway traffic on ordinary open roads and highways.

As the speed demanded is increased it is found that difficulties are experienced which, though diminished, are not altogether removed by the more level alignment of the conductor referred to above as being rendered possible by catenary suspension as compared with car suspension. In the ordinary

Fig. [illegible]

trolley pole with its massive trolley wheel and head is [illegible] the inertia combined with the flexibility, otherwise advantageous, of the moving parts introduces new problems at higher speeds. It must be borne in mind that the kinetic energy of a moving body is proportional to its mass and to the square of the speed. If, therefore, the speed is doubled or trebled, this energy is increased four or nine fold, its tendency being to keep the body moving forward in a straight line. At low speeds the mass is comparatively unimportant, but at high speeds a large mass becomes dangerous. This has led to the heavy trolley pole with its massive head and wheel being replaced by lighter devices which have taken two chief forms: (1) the bow collector and (2) the pantograph collector.

Before describing either of these types it may be remarked here that when the voltage is raised the current to be collected for a given amount of power is correspondingly reduced, and that therefore at the highest voltages used the current for a heavy train becomes comparable with the current ordinarily required for a tramcar at lower voltages, though the insulation must be much more carefully designed.

Bow Collectors.—An early form of bow collector designed as a convenient method of picking up current for ordinary street tramway work is shown in Fig. 1,710, taken from a contemporary illustration in *Cassier's Magazine*, and depicting a tramcar in an Eastern European city in

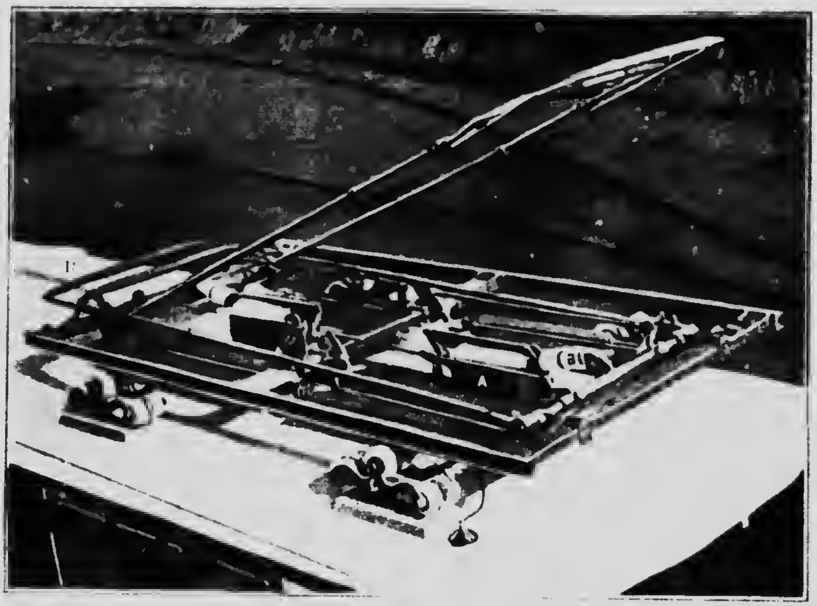
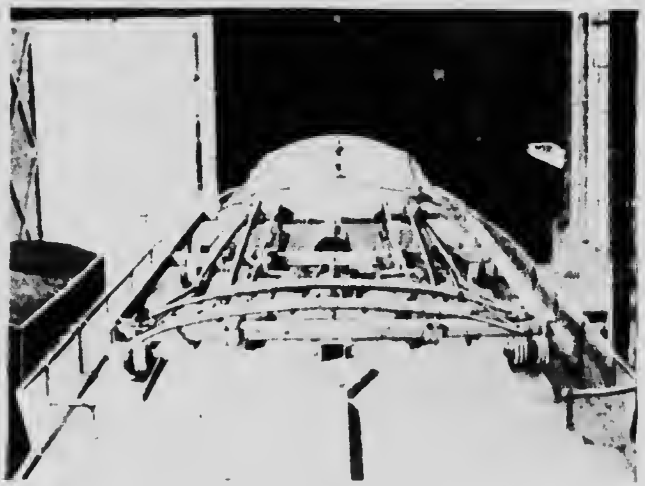


Fig. 1,711. Collector Bows of the L. B. & S. C. Railway in Raised and Lowered Positions

1898. In those early days this type of collector was largely used, being developed quite independently of the trolley wheel and pole, and without the considerations of the requirements of high-speed railway working referred to above. The details of construction of the collector, which is made of light metal rods, are clearly shown. It is mounted on an insulated base, and is pressed upwards by spiral springs in much the same way as a trolley pole. Several forms of this type of collector adapted for tramway and light railway work were designed and used in England and various parts of Europe.

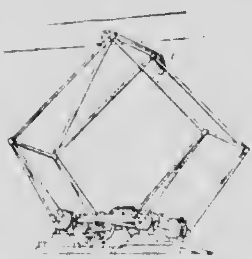
In some cases the bow collector has to be designed to satisfy exceptional conditions, as in the case of the metropolitan electrification of the London

Brighton and South Coast Railway, where the height of the conductor wire varies from 21 feet in the open to 13 feet 10 inches under bridges and in tunnels. Thus in Fig. 1,685 it will be noticed that the vertical height of the conductor at the front of the train is considerably below the height at the rear. The bow collector designed by Mr. Philip Dawson to satisfy these conditions is shown in the raised position in Fig. 1,711. The top portion of the bow is made in two parts, the trailing part being held from the principal bow by means of auxiliary springs; this device is intended to



F[illegible] Bow C[illegible]

prevent interruption of the current caused by the principal bow jumping off the wire, in which case the auxiliary bow at once makes the necessary contact. The bows are held up by springs operated by a piston worked by compressed air. There is another set of bows worked by another piston for running in the opposite direction; this set is shown folded down in Fig. 1,711. Another restriction to be kept in view is that the vertical space available for folding away on the top of the coach is only 12 inches high. When not in use the collectors fold down at B on to the top of the coach, as shown in Fig. 1,712; they are raised from the inside and separate collectors (two in number) are provided for each direction of running. The second collector, as can be seen in Fig. 1,712, is partly raised ready when the first collector is taking the current from a high wire. The strip which makes contact with the overhead conductor is of aluminium, having a deep groove filled with [illegible]. The [illegible] easily renewable and [illegible] the [illegible] conductor wire [illegible] [illegible]able.



[illegible]

Passenger C[illegible] [illegible]

grammatically in Fig. 1,713.* A long collecting piece or shoe *cc*, which may be a simple thick wire or be more complicated in structure, is supported horizontally below the suspended conductor by an articulated structure which takes the form of the well-known pantograph used for copying drawings to a different scale. The general method of articulation is clearly shown in the diagram. The shoe can be raised and lowered vertically by compressed-air mechanism acting on the lower ends of the lower members of the framework. If these ends be slid inwards or outwards or the lower arms rotated, the desired results will follow; the latter is the usual method. In high-voltage working the working mechanism is controlled from the inside of the cab, and is automatically brought into action so as to lower the shoe and break contact if the high-voltage distributing box inside the cab is opened.

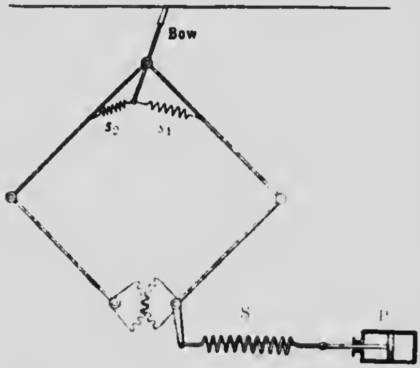


Fig. 1,714. Diagram of Pantograph Mechanism.

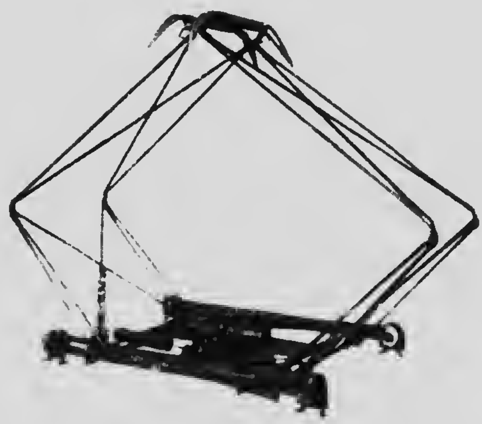


Fig. 1,715.

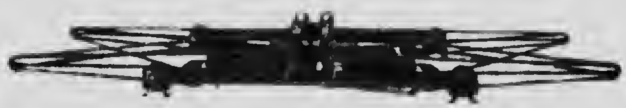


Fig. 1,716.
Side View of Pantograph in Raised and Lowered Position.

One method of operating a pantograph collector by means of compressed air is shown diagrammatically in Fig. 1,714. The lower links of the pantograph on one side form the longer arm of a bent

* From Richey's "Electric Railway Handbook."

lever mechanism, the shorter arm of which is connected, through a coiled spring, S, which acts as a buffer, to the piston rod of a pneumatic engine P. When the piston of the engine moves forward the bow of the pantograph will be lowered, since the corresponding link on the other side is geared to the directly operated link.

The mounting of the contact bow so that the pantograph can be run under the contact wire in either direction is also indicated. The controlling spring S_1 acts against the friction of the contact when the bow is travelling to the left, and if the direction of motion be reversed the spring S_2 will act similarly.

An actual pantograph of a recent type is shown in Figs. 1,715 and 1,716 in the raised and lowered positions respectively. In this method of collection, since the whole of the articulated framework is necessarily "alive," all the apparatus in metallic connection with it must be insulated, and it will be noticed in Fig. 1,715 that the whole outfit, including the operating pneumatic cylinders, is mounted on four insulating stands or feet. The compactness of the apparatus when lowered is very marked.

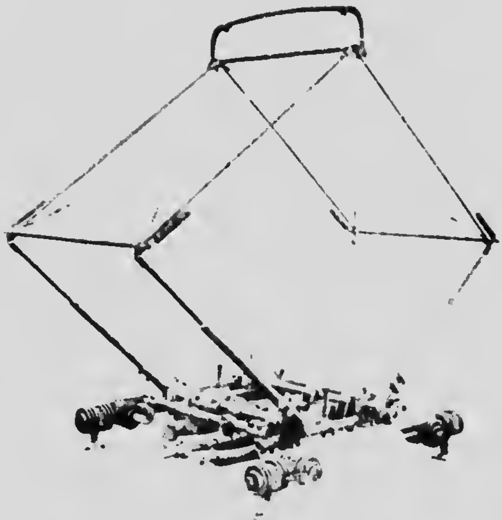


Fig. 1,715.—Bow Type Pantograph [illegible] High[illegible] W[illegible]

The general method of construction of a pantograph collector is such that it can under run the conductor wire in either direction. It is, however, liable at high speeds to "jump" the wire if made in the simple form shown in Fig. 1,713, since the conductor wire is never dead level. Thus, although the pneumatic cylinders and the springs press the contact piece upwards against the wire the whole framework may not be able to follow up a change of level with sufficient rapidity, and the contact will be broken. This leads to destructive sparking and hammer blows as the contact is again made. Moreover, vibrations due to the swaying and jolting of the train have to be provided for. It is therefore desirable that the collector should consist of two parts (1), a main part, comparatively strong and heavy, balanced for wind pressure and provided with springs or other means of exerting a constant pressure irrespective of the position of the shoe, and (ii.) a light auxiliary part, with a much quicker natural period of vibration, and carrying the shoe. The main part will, as a rule, take up the large variations in the height of the wire, whilst the auxiliary part will follow the most rapid vibrations of the car to which it may be subjected.

The provision of the auxiliary part of the collector has already been indicated diagrammatically in Fig. 1,714, and one purpose served by this method of mounting the shoe has been pointed out. Its further usefulness in picking up space lost by comparatively rapid vibrations will now be apparent.

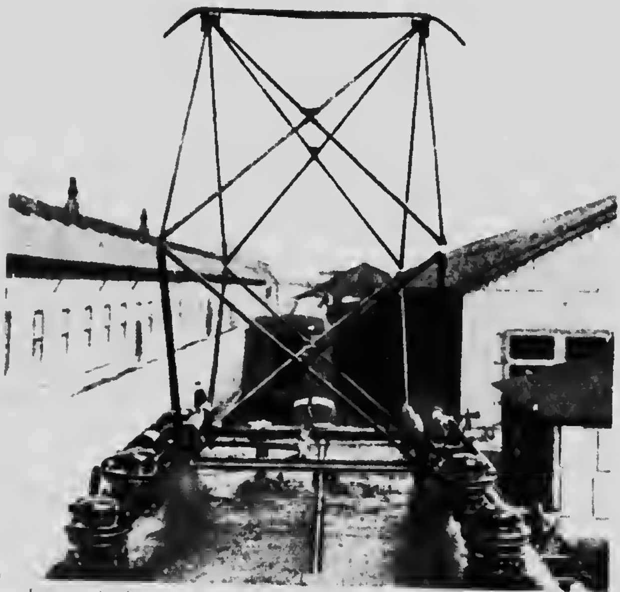
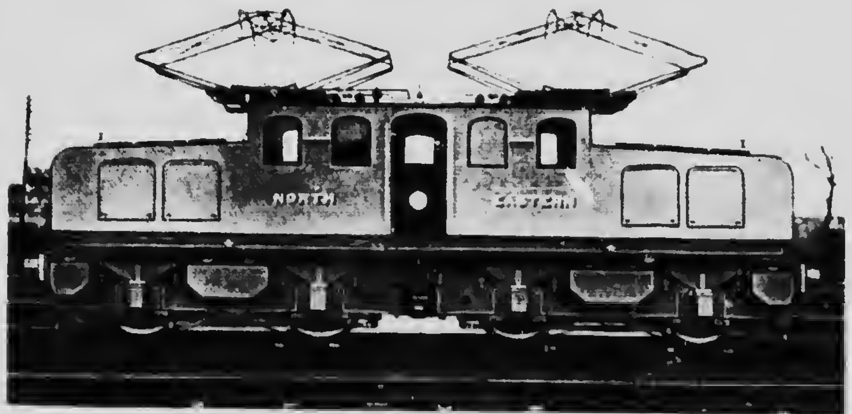


Fig. 1,718. Pantograph for High-voltage Working on the Pennsylvania Railway.

An actual pantograph fitted with its collecting strip or shoe fixed on such a device is shown in Fig. 1,717, which is a view of a pantograph of a standard type fitted by Messrs. Brown, Boveri & Company on the Lötschberg railway. It will be noticed that the auxiliary arch is controlled by four springs, each spring being mounted on one of the upper links of the pantograph. The overhead conductor supported by a single catenary is at a pressure of 15,000 volts, single-phase at 15 cycles. At this pressure the current drawn from the line by the 2,000-H.P. locomotive will be of the order of 140 to 150 amperes. There is an earthing switch at the front and back of each high-voltage switch on the locomotive and this earthing switch is closed whenever the doors of the high-voltage compartment are open.

An end view of a pantograph of especially light construction as used on the Philadelphia Paoli electrification of the Pennsylvania Railway is given in Fig. 1,718. The line voltage here is 11 [illegible] the base of the pantograph is mounted on four insulators suitable for this voltage and these in their turn are mounted on a framework which is again mounted on four more 11,000-volt insulators. The framework of the pantograph is therefore doubly insulated. Instead of a light auxiliary to pick up the rapid oscillations the whole framework is particularly light, and the springs which raise it are designed to give the necessary short-period flexibility. When in operation a slight dragging of the contact shoe results in it following the wire much more closely than with a rigid framework. In addition the shoe itself is spring-mounted on the framework thus increasing its short-period flexibility. Steps for mounting to

Fig. [illegible] View of Pantograph for [illegible]



[illegible] N. E. R. [illegible]

the roof of the car are provided at one corner only, and a lever is placed on the roof at this corner and so arranged that it must be thrown up by anyone climbing up. The effect of throwing up the lever is that the pantograph is dropped and locked in the "down" position, and the entire framework is earthed, thus making the roof of the car safe except for the presence of the "live" wire overhead.

Fig. 1,721.—Side View of N. E. Railway Pantograph, Raised.

To minimise the wear caused by the sliding contact in bow and pantograph collectors, the sliding contact piece has been replaced in some designs by rollers mounted on ball bearings. This takes away one of the advantages of these types, namely, the simplicity and lightness of the actual contact piece and its mounting, and has only been adopted where heavy currents at somewhat low voltages have to be collected. An instance is the 2,400-volt D.C. electrification of the Butte, Anaconda and Pacific Railway in the United States, opened in May, 1913. One of these pantograph-trolleys, as it may be called, is shown, mounted on the roof of the locomotive, in Fig. 1,719. The base follows the usual standard design for high-voltage working, and the arrangements for leading in the current are carefully worked out. The trolley wire is of grooved copper of No. 0000 gauge, equivalent to circular wire 0.460 inch in diameter. Standard side-bracket and cross-span construction are used for the support of the catenary.

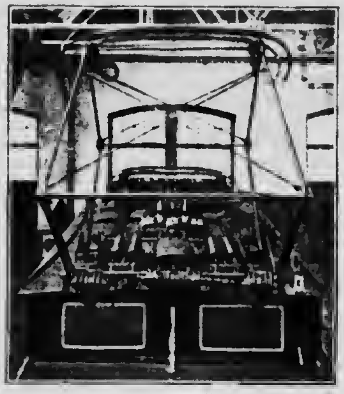


Fig. 1,722.—End View of N. E. Railway Pantograph.

As a final illustration of actual pantographs Fig. 1,720 is taken from a photograph of a heavy freight locomotive used on the Shildon-Newport branch of the North Eastern Railway. The two pantographs are very clearly shown in the raised position, and are a good example of recent practice in England, electric traction on this line having been inaugurated in July, 1915. It will be noticed that the auxiliary part of the pantograph, carrying in each case two contact shoes, is more complicated than in any of the previous examples, and is carefully designed to minimise sparking.

Details of these pantographs on a larger scale are given in Figs. 1,721 and 1,722, of which Fig. 1,721 is a side view of the bows in the running position, and showing the mounting of the double shoe more clearly than in Fig. 1,720. The rubbing parts of these bow shoes are made of aluminium, and each shoe is attached to the pantograph by two separate leaf springs, thus providing for small vibrations and irregularities of level. Fig. 1,722 is an end view of the roof of the cab with the near pantograph raised, and the far one lowered. The mounting of the whole pantograph on strong corrugated insulators is shown as well as other details of the apparatus.

The pantographs are raised by compressed air, and access from the cab to either of the low roofs at the ends of the locomotive can only be obtained through doors, the opening of which releases the air pressure and drops the pantographs out of contact with the overhead conductor which supplies continuous currents at 1,500 volts. These locomotives are designed for heavy freight work, and can haul a 1,400-ton train at 25 miles per hour.

V. Earth Returns and Bonding or Welding

In all the "overhead" systems described in the preceding chapter on electric tramways and in this chapter on electric railways, as well as in the "third rail" and overhead systems described in this chapter, the electric circuit is completed through the running rails, in laying which no attempt is made at electric insulation. In most cases, therefore, the rails are in more or less good electric contact with the surrounding "earth" and this part of the circuit consists of many paths in parallel with the rails between which the current will divide according to the laws of current flow fully set forth throughout this book. This system of "earth returns" as it is not inappropriately called, is based upon the practice and experience of the early telegraph systems which is largely followed in telegraphy at the present day. In the early days of telephony "earth returns" were used but had to be abandoned, for reasons which are set forth in the proper place, in favour of complete metallic circuits carefully insulated.

The traction case which we are now considering is different from the other two long distance cases, inasmuch as the running rails happen, though for other reasons, to be made of material of good electric conductivity which by its large cross-section may offer as good a conductor, per unit length, for the current as the insulated overhead copper conductor. This conductor, moreover, necessarily follows the same route as the overhead conductor, and the wheels of the car or coach offer, as a rule, good conducting contacts through which the current can pass from the moving vehicle to the rail.

At first sight, therefore, it would appear that an almost ideal return

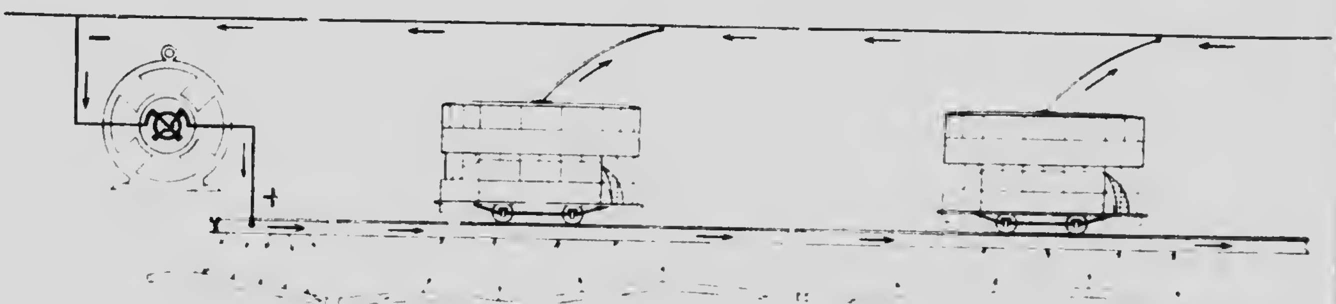


Fig. 173.

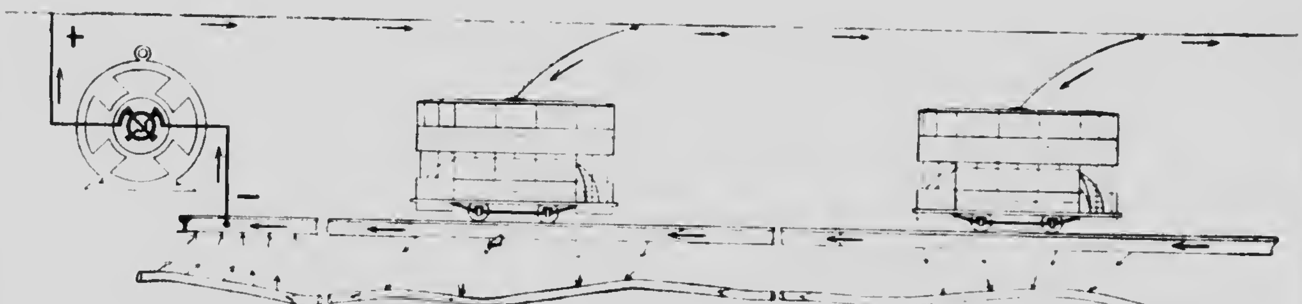


Fig. 174.

Diagram of some Earth-conducted Currents in a Rail-return System.

circuit is provided by non-electrical requirements, and that the expense of providing a return conductor need not be incurred. In actual practice, however, there are drawbacks and difficulties.

The chief difficulties arise from the fact that the running rails, as usually laid for non-electrical traffic, whether on roads or railways, are not electrically continuous. They consist of separate rails of mechanically convenient lengths, but electrically separated, the joints being mechanically bridged by "fish plates" or other devices which may not, and frequently do not, offer a good continuous conducting path across the joint. The electric resistance per mile of the rails may thereby be enormously increased—so much so that, as the rails are uninsulated, the surrounding ground, though of poor conducting material, has, by reason of its large section across the direction of current flow, a sufficiently low electric resistance for appreciable quantities of the total current to be diverted. The ground between the moving car or train and the generating or sub-station from which the electric energy is drawn thus becomes filled with electric currents which may be of considerable magnitude, completing their circuits by the lines of least electric resistance.

This state of affairs is shown diagrammatically in the simplest case in Figs. 1,723 and 1,724, in which a continuous-current dynamo is portrayed as supplying energy by an overhead wire to a distant moving tramcar. In one case (Fig. 1,724) the + pole of the dynamo is connected to the insulated overhead conductor, and the current after passing through the motors on the car finds its way to the rails through the wheels and back to the dynamo as shown. In Fig. 1,723 the polarity is reversed, and the current from the dynamo first passes to the rails and the earth in parallel with them, reaching the car through its wheels, and after passing through the motors, etc., on the car, returns to the dynamo *via* the overhead insulated conductor.

Electrically each of the stray paths by which any portion of the current passes between the dynamo and the car lowers the total resistance of the circuit, and therefore, at first sight, would appear to be advantageous. Trouble arises, however, from the nature of these paths. In all modern towns and districts there are in the ground permeated by these currents networks of water, gas, and sometimes other, metallic pipes which, especially the first-named, offer good conducting paths for the currents for some portion of the distances to be traversed, and the conditions are such as to bring into play other properties of the current, and more especially the chemical effect so fully described elsewhere.* The results may be disastrous to these complacent conductors, one of which is represented in the diagram as following roughly the route of the tram line, a case which may not unfrequently occur in practice.

* *See* Vol. I., Chapter V., and elsewhere.

Electrolytic Corrosion.—Wherever metallic pipes or structures are buried in damp soil, which often contains electrolytic salts such as nitrates or chlorides, the conditions for one of the electrodes of an electrolytic cell exist, and if the current be passing from the metal into the soil the former becomes the anode and is corroded. If the current be passing in the opposite direction, that is, from the moist soil to the metal, this metal acts as a kathode, and is not corroded, but is plated with hydrogen or some electro-positive metal.

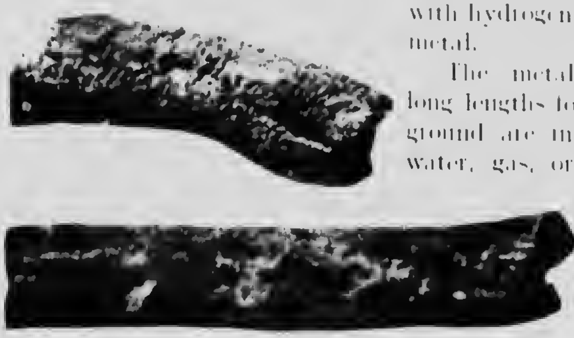


Fig. 1,725.—Lead Water-pipes Corroded by Electrolysis.

The metals commonly buried in long lengths for useful purposes in the ground are in the form of pipes for water, gas, or various kinds of conduits, and the sheathing of electric cables of all kinds, and in many cases some of these, as just mentioned, will be found running fairly parallel with the track rails as indicated in Figs. 1,723 and 1,724. The materials are almost invariably lead, or wrought-iron, steel, or cast-iron, and of these lead is the most readily corrodible, whilst cast-iron, especially of the kind that contains fairly large percentages of carbon and silicon, is least affected; wrought-iron occupies an intermediate position.

Examples of the corrosion of lead water-pipes are given in Fig. 1,725,* and the corrosion of the sheathing of a telephone cable which was laid under the rails of an electric tramway is shown in Fig. 1,726. It should be noted that the corrosion is not uniformly distributed over the surface of the metal, but attacks some parts more persistently than others. This is what might have been expected from the usual effects which have been described elsewhere, of "local action" in electro-chemical combinations, for the surfaces of these conductors under the conditions of manufacture and laying cannot be supposed to be homogeneous. The result is that the metal is not removed in successive layers as a whole, but becomes deeply pitted in parts until at some of these it is eaten right

Fig. 1,726.—Corroded Lead-sheathed Telephone Cable Run Below an Electric Tramway.

* This and Figs. 1,726 to 1,728 are taken from *Cassier's Magazine*.

away, and its usefulness for the purpose for which it was laid down is either impaired or absolutely destroyed.

The corrosion of iron water pipes is shown in Figs. 1,727 and 1,728, the former being deeply pitted, and the latter being eaten completely through. It should, of course, be remembered that pipes containing water under pressure will be torn open by the water at weak points before the corrosion has worked completely through the material.

On the supposition that the particular pipe network is electrically continuous between the generating or cable station, and the moving tram car, Figs. 1,723 and 1,724, show where the corrosion is most likely to take place in the two cases depicted. In Fig. 1,724 where the + pole of the dynamos is connected to the *trolley wire* the underground pipe systems act as part of the return circuit, and become anodes and are corroded close to the station. In Fig. 1,723, where the *rails* are connected to the + pole, the pipe systems act as part of the outgoing circuit and become anodes in the neighborhood of the moving tram car or tram cars. In the former case the corrosion area is concentrated in the vicinity of the station, whereas in the latter it is spread all over the tramway system.

Fig. 1,727.

Fig. 1,728.
Corrosion of Iron Water-pipe

Remedies. The most obvious remedy, since the corrosion will, according to known laws, depend on the volume of the leakage currents is to diminish if possible the conductivity of the other parallel circuits, and to improve the conductivity of the rail. Little can be done in the former direction, but it may be pointed out that as ordinarily laid in concrete the rails do not offer a good "earth" in dry weather, and even in wet weather the leakage, which will chiefly start from the rails as a surface leakage, cannot be great if the potential difference between the moving car and the station be not very great. This will depend on the conductivity of the rails, and the current density in them.

A word of caution is perhaps necessary here. It must not be supposed that even if the mischievous currents could be measured, which is practically impossible, the amount of corrosion in a given time could be calculated by Faraday's simple laws. The conditions are too complicated and the "current efficiency" is low. In D.C. systems corrosion may be diminished by periodically reversing polarity. Theoretically there should be no corrosion with A.C. systems, since corrosion in one half-cycle should be counteracted by the opposite effect in the succeeding half-cycle. In practice, however, there is corrosion, but it is much smaller than with D.C. systems, and there is probably a limiting frequency which is different for iron from what it is for lead. We regret we cannot pursue the subject further.

The matter is of sufficient importance for the issue of definite regulations by the Board of Trade, which are too voluminous to quote *in extenso*, but of which the following are the more important. In the first place the Board requires the uninsulated return to be connected to the — pole of the generator, thus insisting on the connections shown in Fig. 1,723. This makes it easier to localise any mischief, for the pipe anodes, if any, will be near the station. The regulations also require the tramway company to keep continuous records of the P.D. between points on the uninsulated return, and "if at any time such P.D. between any two points exceeds the limit of 7 volts the company shall take immediate steps to reduce it below that limit." There are also regulations for testing the P.D. between the uninsulated return and any pipe in the vicinity, and when the latter is the higher (so that it would act as an anode) the difference must be less than that of a Leclanché cell, i.e. less than 1·5 volts.

Necessity for Rail Bonding. All this points to the necessity for maintaining the conductivity of the uninsulated return rails as high as possible. The weak places in the electric conductivity of the rails are, as pointed out above, at the joints, and the simplest way to improve the conductivity and thus diminish the potential difference and the leakage is to use an efficient system of bonding or jointing, which make the joints as good conductors per unit length as the rails themselves. The two methods indicated are:—

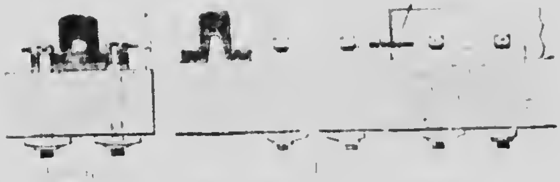
(i) The fixing of jumpers or "bonds" as they are called for carrying the current across the bad electrical joint.

(ii) The abolition of the mechanical joint by welding together the butted ends of consecutive rails in such a way that the electrical conductivity of the welded joint per unit length shall be at least as high as that of any part of the uninsulated rail.

It may be objected with regard to (ii) that in such continuously solid rails no allowance is made for contraction and expansion during extremes of winter and summer temperatures, but it can be shown, and experience confirms the calculation, that the strains whether tensile or compressive introduced by such differences of temperature are well within the elastic limits of the materials used and that they are therefore practically negligible.

The necessity for efficient bonding or welding at the joints when the running rails are used as part of the circuit, also exists in the conductor rails when these are insulated, as in the third rail and other systems, and carry the whole current of the section. Like the running rails, the conductor rails have to be made in manageable lengths, and electrically bad joints must occur at intervals, even though, as described at p. ..., several lengths may be united into an electrically single rail ... feet long. Further, in the case of insulated conductors the joint is necessarily directly in the circuit, and no relief from the drop of volts caused by relatively high resistance in it can be obtained by leakage through adjacent conductors. The loss of energy due to a bad joint can be avoided by the same remedy as in the other case, namely efficient bonding, and as the types of bond used are similar and often identical in the two cases, it will be convenient to describe these types without distinguishing them except in special cases.

Bonds. The conditions to be fulfilled are simple, namely to provide a short length of a low resistance conductor with proper terminals or electrodes which can be electrically connected, readily and economically, to the rails on the two sides of the gap to be bridged.



Figs. 1,729, 1,730.—Track Bonding, Central London Railway.

In the tube railways in London the conditions which influenced the form of bonds to be used on the track rails were obviously simpler than they are on open railways or even in ordinary tunnels. The form of bonding adopted in 1900 on the track rails of the Central London Railway is shown in Figs. 1,729 and 1,730, of which Fig. 1,729 is a cross-section, and Fig. 1,730 a side view, but with the end of the rail shown diagrammatically in section. The joint at A is double bonded with flexible bonds of the type then known as crown bonds, the terminals of which were forced into holes in the flanges which form the foot of the rail. Space for installing the bonds was obtained by inserting a wooden packing below the rail at the joint. The scale of the drawing is ...th, and it may be of interest to note that the rails weighed 100 lb. per yard, the third or insulated rail being of special conductivity steel (see p. 1523) weighing only 85 lb. per yard.

The *material* almost universally used at the present time for the bond conductor is copper, obviously because of its high conductivity, which makes a much smaller cross-section electrically equivalent or more than equivalent to the massive rail in current-carrying capacity. The copper used should be soft and dense; hard copper is liable to crack when compressed, and does not bond intimately with the steel of the rail if mechanical methods of making the joint are used. The body of the bond should be flexible if it is to be durable under ordinary conditions. If too stiff the vibration and movement caused by passing traffic causes the copper to crystallise, and sooner or later to break. Moreover, it is desirable, in the interests of rapid and economical installation, that the distance apart of the terminals should be easily adjustable within certain limits.

Form of the Bond Body.—The simplest form of the conductor is a *solid* and therefore a relatively inflexible rod either round or flattened as in the

Fig. 1,731. Examples of Solid Bonds.

group of bonds shown in Fig. 1,731, which is taken from a photograph supplied by the British Insulated and Helsby Cables, Limited. Such bonds are usually employed for special work, and also to bridge over the whole length covered by the fish-plates, and running outside these plates are exposed to rough usage. They should not ordinarily be used in positions where they are subjected to vibration, as they are liable to break.

An example of the use of such bonds is given in Fig. 1,732, but the electrodes are not the same as in Fig. 1,731. For the particular work shown, which is rather special, they are more suitable than some of the other forms.

Fig. 1,732. Solid Bonds in Use.

To secure the flexibility referred to above, and which is so desirable, the body of the bond is frequently *laminated* either by being formed of thin strips of copper as in Figs. 1,733 and 1,734 which are examples of bonds made by the Forest City Electric Services Supply Co., of Manchester, or of stranded wires as in Figs. 1,735 and 1,736, these bonds being as made by the Electric Service Supplies Co., of Philadelphia. The bonds shown in these figures, for reasons which will appear presently, consist of two sets of conductors in parallel, and are of what is known as the "protected" type, that is, they can be installed, as is shown later, underneath the fish plates, which will then protect them from mechanical injury. In Figs. 1,733 and 1,735 the two sections are of equal carrying capacity, whilst in Figs. 1,734 and 1,736, the upper section is smaller than the lower for reasons to be explained presently.

Fig. 1,733.—Laminated Double Bond.

The crimp in the middle of both sets of strands is to allow for expansion on heating, and also for the slight adjustment, referred to above, of the distance between the terminals when installing. These crimps may be and are, when necessary, placed in other parts of the laminated conductors. The stranded cables may also be pressed into a square or rectangular section so as to fill the available space as completely as the strip cables.

Fig. 1,734.—Laminated Double Bond (unbalanced).

The great variety of forms and relative dimensions of modern rail bonds may be partially gathered from an inspection of Fig. 1,737, which is reproduced from a photograph of a group of laminated, stranded and solid bonds manufactured by the British Insulated and Helsby Cables, Limited. It will be realised that bonds can be supplied to satisfy any of the widely varying conditions occurring in actual practice.

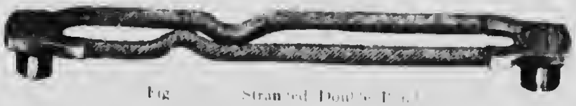


Fig. 1,735.—Stranded Double Bond.

Forms of Terminals.—Two requirements have to be borne in mind in designing the electrodes or terminals: (i.) a good method of attachment to the copper conductor, and (ii.) a method of fixing the bond to the steel rail so as to ensure (*a*) good electrical contact of negligible resistance, and (*b*) good mechanical contact not liable to work loose under service conditions.

Fig. 1,736.—Stranded Double Bond (unbalanced).

The first requirement, which would appear to be easy to meet satisfactorily, is not so simple as it seems to be, for it has been asserted that 90 per cent. of the rail bond troubles occur at the junction between the cable and the terminal. Mere sweating or soldering of the end of the wires into a thimble is not desirable, as this may mean overheated or burnt copper at the critical point, such copper being liable to crystallise and become mechanically weak. One method of meeting the difficulty, adopted by the Electric Service Supplies Co., is the "shot-over" sleeve, which gives a joint such as is shown in Fig. 1,738, in which the terminal has been cut longitudinally to show the result attained. The sleeve of the terminal is seen to project over the copper strands whose ends have been

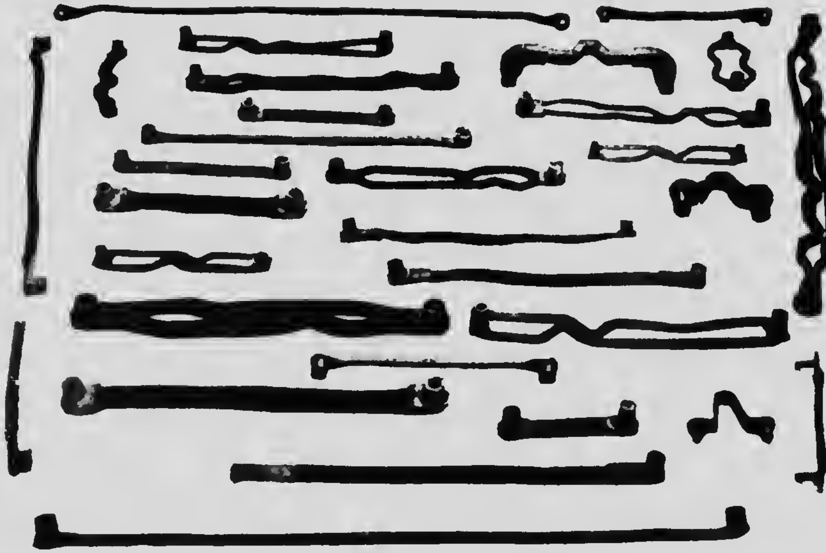


Fig. 1,737.—Examples of Various Rail Bonds.

quite welded into the mass of the copper of the terminal. This has been accomplished by forging and welding between the dies shown in Figs. 1,739 and 1,740, in which Fig. 1,739 shows the copper strand c inserted in the thimble T, and the forging dies *d* and D in position at the beginning of the process, whilst Fig. 1,740 shows the final result with the dies closed down. The shape of the upper die accounts for the "shot-over" sleeve, and the necessity for having soft copper is apparent.

Fig. 1,738.—Section of a Shot-over Sleeve.

The necessity for careful design for making good electrical and mechanical connection between the copper terminal and the steel rail is very obvious. It is possible to weld the two together by arc or oxy-acetylene processes, but purely mechanical methods are simpler, and will be described first as they are very widely employed. The bonds so far illustrated, Figs. 1,731 to 1,738, are designed for such methods. An inspection of these figures will reveal that the forms of the terminals or electrodes illustrated is such that they are intended to be inserted in suitable cylindric holes in the steel rails. There is, however, a difference in this respect between Figs. 1,733 to 1,735 on the one hand, and Fig. 1,736 on the other, a difference which also appears in the bonds illustrated in Fig. 1,737. In Figs. 1,733 to 1,735 the pin, which is about ¾ inch in diameter and ¾ inch long, is a *solid* cylinder, whilst in Fig. 1,736 it is a *hollow* cylinder of the same external dimensions. The first form of terminal is designed for the "compressed-terminal" method of jointing, and the latter for the "pin driven" method.

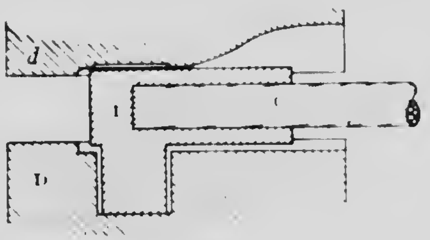


Fig. 1,739.

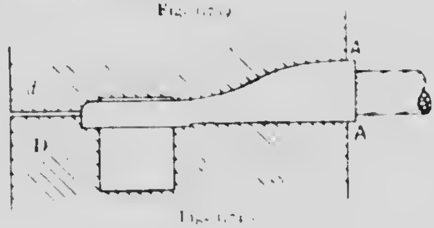


Fig. 1,740.
Forging and Welding a Shunt over Sleeve.

In the "*compressed-terminal*" method the solid cylinder is inserted into a carefully drilled and quite clean hole in the steel rail which it fits closely, and is then either hydraulically or mechanically compressed as shown in Figs. 1,741 to 1,743, for which the author is indebted to the Forest City Electric Services Supply Co. Fig. 1,741 shows the compressor die D opposite the plug P inserted in the rail R; in Fig. 1,742 the work of the compressor in forcing the copper back into the hole has commenced, and the excess copper is flowing round the ends of the die and of the hole. The whole of the copper is under compression, and is completely filling the hole. Fig. 1,743 shows the finished joint; the powerful forces employed have, it is found, caused the copper to flow into every little inequality in the bond hole in the steel, the result being an intimate moisture-proof contact

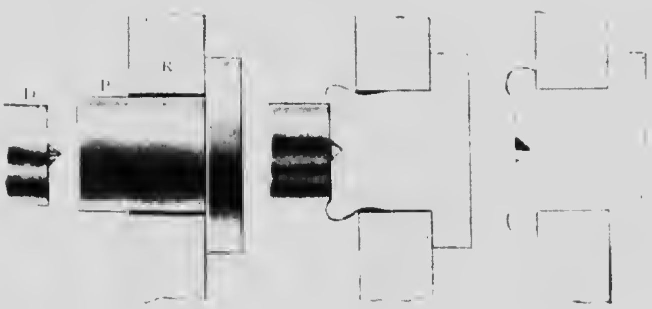


Fig. 1,741. Fig. 1,742. Fig. 1,743.
The Compressed-terminal Method of Fixing Rail Bonds.

between the copper of the bond and the steel of the rail, a contact which should retain its efficiency for many years.

The "*pin-driven*" method of fixing the bonds to the rails is illustrated in Fig. 1,744, for which the author is indebted to the Electric Service Supplies Co. The web R of the rail is drilled and a hole of the proper size provided, into which the hollow cylinder terminal I of the bond can be inserted. Both the inner surface of the hole and the outer surface of the copper terminal should be perfectly clean and especially free from grease and oil. The taper punch P, which, at its greatest diameter is $\frac{1}{16}$ in. larger than the hole in the terminal, is then driven clean through that hole, expanding the copper against the inner surface of the hole in the iron and bringing the iron and the copper into intimate contact. The job is finished as shown at A, by driving home the drift pin *p*, which is $\frac{1}{32}$ in. larger in diameter than the hole left by the passage of the taper punch; some of the copper is driven forward and forms the far side of the web a burr which grips the iron somewhat like a rivet head.

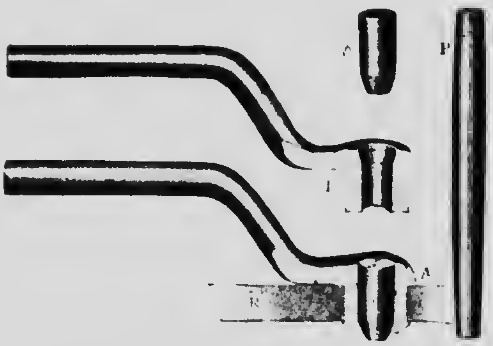


Fig. 1,744. Fixing a "Pin-driven" Bond Terminal.

The advantages of the method are that no special tools, only a hammer and a taper punch, are required, and the work can be done rapidly and economically. The disadvantage is that notwithstanding the precautions taken, the joint may work loose in the course of time, because of the severe vibrations set up by the traffic passing along the rails.

The excessive vibrations which are set up at the joints of the running rails by the traffic, severely strain any form of mechanical joint between the rail and the bond, which necessarily has to be placed at this point where vibration is at its worst. Several methods of brazing or welding the bond to the rail have therefore been devised. The subjects of electric brazing and welding are dealt with in a subsequent chapter (Chapter XXV.), where we propose to deal with their application to rail bonding.

Methods of *welding* are based on the use of molten copper and suitable moulds, the molten copper being either (i.) procured from a small furnace forming part of the movable plant and having an electrically-driven blower, or (ii.) obtained *in situ* by melting some of the copper of the terminal by an electric arc. In both cases the heat in the molten copper is relied upon to bring the steel of the rail at the terminal up to a welding temperature.

The oxy-acetylene gas jet has also been used for the purpose, as shown in Fig. 1,745, which illustrates an outfit devised for the purpose by the Ohio Brass Co. The operator is holding in his left hand a rod of brazing flux, and by means of the oxy-acetylene flame is welding the bond to the bulb of the rail.

Protected Bonds. The bonds shown *in situ* in Fig. 1,730 are not under any kind of cover, but are freely exposed to the weather and mechanical injury, and what is sometimes more important to the depredations of marauders. Copper, although not one of the precious metals, has a commercial value sufficiently high to make it worth while to cut the metal out of a bond so exposed. It, therefore, without a prohibitive addition to the cost, the bond can be covered up, several advantages accrue. Fortunately the fish-plates necessary for the firmness of the mechanical joint can be utilised for the purposes, and hence bonds designed to be placed underneath the fish-plates on the web of the rail, are widely used, and are often referred to as "protected" bonds. [illegible] three examples will suffice to expound the principles involved and their application.

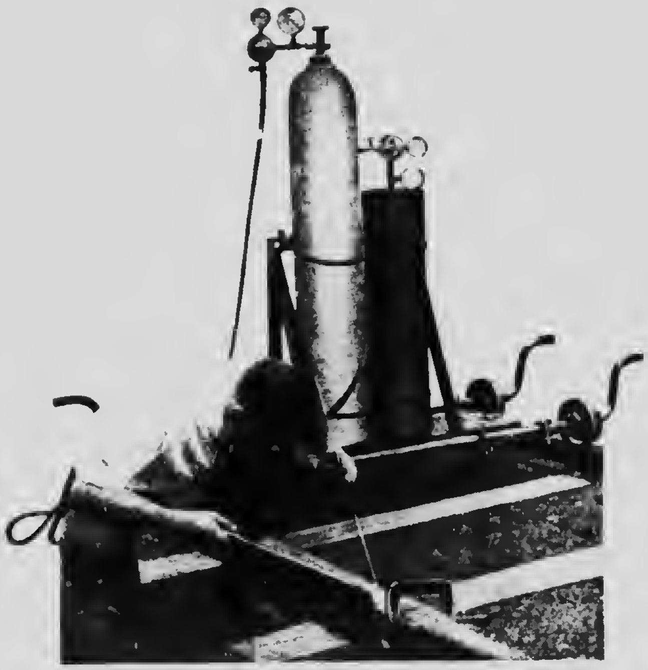


Fig. 1,744.—Oxy-acetylene Welding of Rail Bonds.

A simple case with flat iron for the fish-plates and with the bonds on one side only of the web is shown in Fig. 1,7[illegible]. Two bonds are used, the lengths being different in order that the holes for fixing the bonds may be so placed as not to weaken the web seriously. The position of the holes for bolting on the fish-plates have to be taken into account; these positions are shown in the figure. A single bond with a cross section of copper equal to those of the two separate bonds added together would be liable to terminal difficulties. It should be noted how the kinks in the copper strips enable the terminal holes to be advantageously placed.

It is frequently considered worth the trouble and expense to have more elaborately shaped fish-plates, such as are shown in Fig. 1,747, in which the two bonds for double bonding are placed one on each side of the web. The position of the bond on the far side is indicated by dotted lines, but the ends of its terminals appear at *tt*. The web is pierced with eight holes all on the same horizontal line, four of these being for the bond terminals and four for the bolts for holding the fish-plates. The bonds shown are unbalanced bonds (*see* Fig. 1,73[illegible]), as there is more room at the bottom than at the top of the cavity.

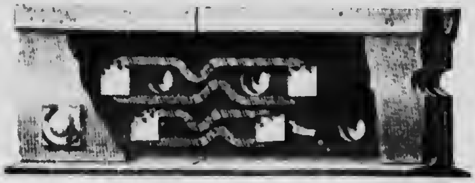


Fig. 1,746.—Double Bonds Protected by Flat Fish-plate.

Conductor Bonding. The mechanical conditions at the joints not being so rigorous in conductor rails as they are in running rails, the work of bonding is rendered simpler. There is no longer any necessity to "protect" the bonds as in the other case, for a high-voltage "live" conductor is electrically protected from interference.

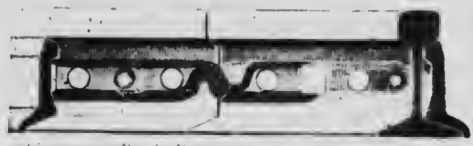


Fig. 1,747.—Bonds Protected by Special Fish-plates.

The bonds used for the third rail in the earliest enclosed railways were quite simple, as will be evident from an inspection of Fig. 1,748, which shows the bonding of the insulated conductor rail installed on the Liverpool Overhead Railway, in 1893. Double bonds are used, bolted, one on each side, to the flanges of the channel-iron rail. The mounting of the rail will be found illustrated in Fig. 1,644.

In modern third-rail systems what are known as "foot bonds" are frequently used, these being bonds which are placed across the joint underneath the rail. Space is always available, as a joint is never placed at an insulator.

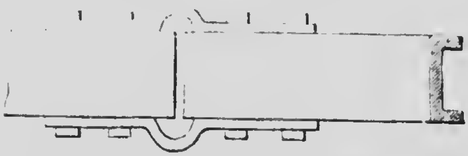


Fig. 1,748.—Bonding Conductor Rails, Liverpool Overhead Railway ([illegible]).

Such bonds have already appeared in some of the previous illustrations, e.g. Figs. 1,661, 1,662 and 1,664, which should now be referred to in this connection. The joint shown in these figures is an expansion joint, which is used every 300 feet, and four-foot bonds are used to carry the current across the gap. At intermediate joints in the 60-foot third-rail conductors there is no provision for expansion, and the bonding is as shown in Fig. 1,749, which gives a section and side view, partly diagrammatic, drawn to ¼ scale. Here also there are four bonds, but two of them are under the fish-plates, both on the same side of the rails, and two are under the flanges

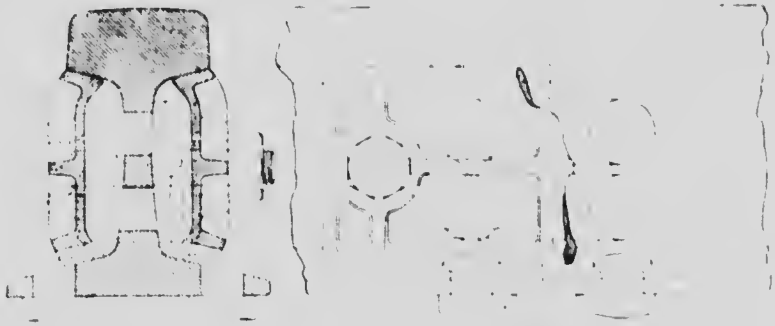


Fig. 1,749.—Bonding on the Manhattan Railway ([illegible]) at an Intermediate Joint on the Third Rail

of the foot of the rail, one on either side. To simplify construction all the holes, whether for bolts or bonds, are of the same diameter, namely ⅞ inch.

On the more recent (1914) electrification of the London and North Western Railway metropolitan suburban electric system, the positive conductor rails are bonded as shown in Figs. 1,750 to 1,752. An identical method was used at about the same time by the London and South Western Railway. Fig. 1,750 is a cross-section near the bond, and gives the dimensions of the plugs. Fig. 1,751 is a side view giving the positions of the plug-holes; and Fig. 1,752 is a plan giving further dimensional details. It will be noticed that the rail gap is ¼ inch. The four bonds, two short and two long, are of the flexible-strip type with solid-drop forged heads, which are forced into holes bored in the flanges of the foot of the conductor rail by hydraulic pressure. The holes are 1 inch in diameter,

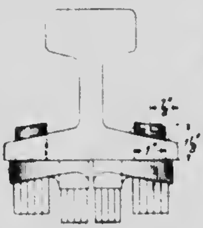


Fig. 1,750.

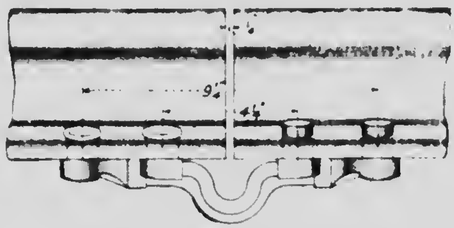


Fig. 1,751.

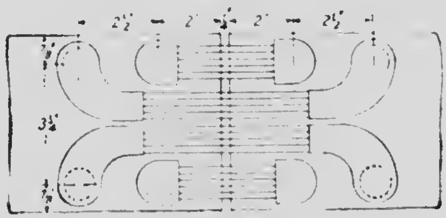


Fig. 1,752.

Figs. 1,750 to 1,752.—Bonding of the Conductor Rails on the L. and N. W. Railway (1914) and other dimensions are as given in the figures. The four bonds have a sectional area of 1·4 sq. in., which is rather less than the equivalent section of the rail.

As an additional example Fig. 1,753 is a view of the bonding of a joint on the third rail used in the Pennsylvania Railway Tunnel under the Hudson River. The currents are large and the rail is correspondingly heavy, i.e. 150 lb. per yard. Consequently the bonds, of which there are four at each joint, are also heavy, the total cross-section of the copper being more than 1·4 sq. in. The electrodes are of the "compressed terminal" type, and are attached to the lower flange of the rail, the holes in which are punched with a hydraulic punch, capable of giving a thrust of 100 tons. The terminals are compressed by a hydraulic compressor with a maximum thrust of 35 tons. The bonds and tools are made by the Electric Service Supplies Co. The figure also shows two of the insulators supporting the rail.

Fig. 1,753.—Bonding of Conductor Rail in Hudson River Tunnel.

Bonds as Feeder Points. The "foot bonds" just described may readily be utilised, as shown in Fig. 1,754, for feeder connections or "taps" for supplying current to the conductor rail, or for connecting up jumper cables when the conductor rail is interrupted or changes from one side of the line to the other. These bonds, which are manufactured by the British Insulated and Helsby Cables, Limited, have the connector securely welded to the copper of each bond, and are sent out as shown quite ready for fixing to the rails. Another example, where a different form of terminal is employed and where the conductor is laminated, is shown in Fig. 1,755. The pattern is one made by the Forest City Electric Services Supply Co., and the figure is self explanatory.

Fig. 1,754.—Straddle Double Bonds with Cable Connector Attached.

Testing Bonded Joints. The conductivity of the bonded joint being the important factor, it is very necessary that this conductivity should be rigorously tested, not only when the bond is first installed, but also periodically to ascertain whether the original conductivity is being maintained.

The most convenient way of stating the result is not to express the resistance of the joint in microhms, but in terms of the resistance of a standard length of the rail on which it is placed, and this leads to methods of testing in which the resistance of the joint is compared directly with the resistance of a length of the actual rail in its vicinity. Any of the simple methods described elsewhere in this book for comparing resistances may be employed, but usually either the Wheatstone bridge method or the fall of potential method is convenient, and special portable apparatus can be devised. The fall of potential method is the simpler, and can be used when the current in the rails is sufficient to secure a fall of potential large enough to ensure that the apparatus shall be sufficiently sensitive. Where this is not the case, a battery must be used.

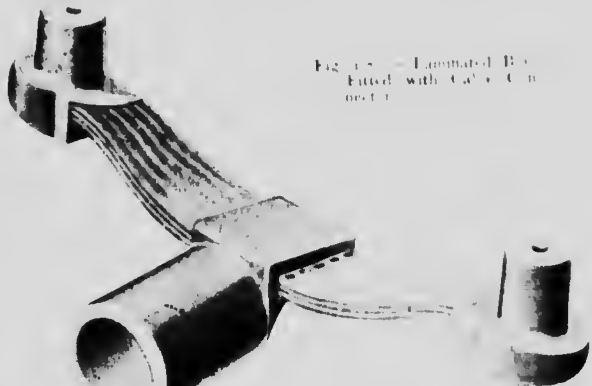


Fig. 1,755.—Laminated Bond Fitted with Cable Connector.

Full details of both methods need not be repeated here, but a few words as to the special apparatus designed for these tests may be of interest. The connections for a fall of potential test are given in Fig. 1,756. A non conducting contact bar, A C, carries three contact pieces, the gaps A B and B C being equal, say 3 feet; these contact pieces are placed on the rail so that one gap, B C, bridges the joint to be tested, and the other an equal length of unbroken rail. One terminal of the galvanometer, G, is attached to B, and the other to a contact arm, *b*, the end of which can be moved over a circular rheostat. Auxiliary resistances R_1 and R_2 are introduced on either side of the galvanometer, such that R_1 plus the whole of the rheostat resistance from *a* to *c* is equal to R_2. The pointer *b* is to be moved until the galvano-

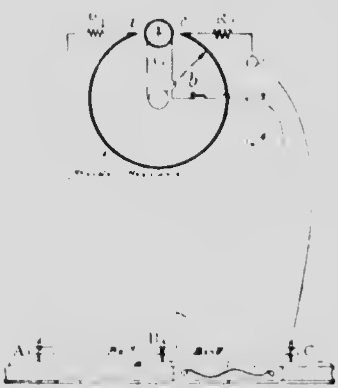


Fig. 1,756.—Connections for a Bond Testing Set.

meter shows no deflection, and should then indicate on a scale the resistance of the joint in terms of the resistance of so many feet of the rail. The two terminals of the galvanometer should be at the same potential and the galvanometer needle at zero when

Fig. 1,757.—Details of Contact Pieces for Bond Testing.

$$\frac{r + R}{R} = \frac{R_1 + cb}{R_1 + ab} \quad . \quad . \quad . \quad (1)$$

where R is the resistance of the length AB (= BC) of the rail and r is the resistance of the joint. From equation (1) it can be shown that

$$\frac{r}{R} = \frac{2cb}{R_1 - cb} \quad . \quad . \quad . \quad (2)$$

which shows that $r = 0$ when $cb = 0$, that is, when b is on c. The zero reading of the rheostat scale is therefore at c, and if the gap be 3 feet long and R be taken to = 3, the scale can be marked off giving the resistance r for different positions of b in terms of the resistance per foot of the rail for all sizes of rails.

It is essential that there should be good contacts at A, B and C, but especially at A and C. Details of the actual contacts on the contact bar used by the Electric Service Supplies Co. are shown in Fig. 1,757, and the making of a test in Fig. 1,758. The actual contacts on the rail are made by short pieces of hack-saw blades fastened by clamps, and the mounting is such that when the handle of the bar (Fig. 1,758) is rocked at right angles to the rail the blades saw their way through any dirt or scale with which the surface of the rail may be coated.

Fig. 1,758.—Testing a Rail Bond.

Another method is to have the contacts A and C adjustable on a graduated bar, and to adjust until the falls of potential across the gaps AB and BC are equal. Still further modifications are obvious, as is also the use of the three-point contact bar for a Wheatstone bridge test.

The bonded joints should, as already remarked, be tested periodically, a careful record should be kept of the results of the tests, and any serious deterioration in any point should be immediately investigated and the cause removed.

Rail Welding. The second method (*see* page 157) of ensuring the electrical continuity of the return path *via* the rails consists in abolishing the cause of the discontinuity, the mechanical joint between consecutive rails. This is accomplished by welding together the butted ends of the rails instead of using fish plates or other mechanical devices for keeping the rails in true alignment. If this welding, which must be done *in situ*, can be successfully carried out without affecting the mechanical properties of the rail, the rail becomes both mechanically and electrically continuous, and the mechanical advantages should be no less pronounced than the electrical. The difficulties of keeping in good condition an ordinary mechanical joint, however well designed and constructed, are greater on street tramway lines than on railways, since the street rails are buried, and it is not possible to tighten up the fastenings periodically and frequently as they shake loose under traffic conditions. A slight defect in alignment and level causes the joint to be subjected to hammer blows by the passing car wheels, and the mischief rapidly increases when once started. The elimination of these hammer-blows considerably increases the life of the rails.

Moreover, the boring of holes in the webs of the rails for the bolts of the fish plates weakens the rails just at the places where special strengthening is needed. On the other hand it is difficult, if not impossible, to weld the butted ends of rails together without overheating the rails for an appreciable distance on each side of the joint, and thus neutralising, again at the critical points, the effects of the heat-treatment to which the material was carefully subjected during the manufacture of the rail.

Cast Welding. The outstanding advantages of the continuous rail were, in the early days of electric tramway development, considered to be so marked that the serious difficulties of welding the rails together in their final positions on the road were faced and to some extent successfully overcome by a process known as "*cast welding.*" This consisted in pouring molten cast iron into and round the slot between the two rails, the iron being at a temperature well above its solidifying point so that heat was available for incipient melting of the surfaces to be welded before the mass set, thus ensuring a good weld. The molten metal had obviously to be held in its place, and therefore a proper mould with gates, risers, etc., had to be built up round the joint; moreover, to ensure a good joint the sides and bases of the rail ends had to be well cleaned with a sand blast. The difficulty which was perhaps the greatest, that of obtaining a supply of molten iron on the spot, was overcome by constructing a small travelling cupola with the air blast supplied by an electrically driven fan. We do not give further details or illustrations of the process, as it has, for all practical purposes, been superseded for many years by other processes.

Thermit Welding. The central operation of this process is the production from the cold in 30 or 40 seconds of a white hot mass of molten iron or steel by means of a chemical reaction which, when once started, is

Fig. 1,759.—Rail Welding, "Insert" Thermit Method

completed automatically. A mixture of powdered aluminium and ferric oxide does not undergo any change at ordinary or even fairly high temperatures, but when any part of the mass is heated sufficiently the following reaction takes place :—

$$2Al + Fe_2O_3 = Al_2O_3 + 2Fe$$

In other words, the oxygen is transferred from the ferric oxide to the aluminium, which becomes aluminic oxide or alumina, and the iron is reduced to the metallic state. The process is endothermic, that is, when the reaction starts in any part of the mass, [illegible] is liberated which raises the temperature of the surrounding ma[illegible] above the reaction temperature, and the reaction is continued and [illegible]ads rapidly throughout the whole mass. In fact, one of the difficulties of the practical application is that the temperature produced (about 2,750° F.), if the proper proportions of the material be taken, is excessive and special devices, such as the [illegible] [illegible], are employed to reduce it. To start the action a [illegible] cartridge is used, in which barium peroxide (BaO_2) takes the place of the ferric oxide in the thermit mixture. The chemical action is similar, but commences at a lower temperature, as the reaction in a mixture of barium peroxide and powdered aluminium can be started by an ordinary match.

The success of the process depends upon careful attention to a number of small details which will be best understood from a description of one of the recent methods of carrying it out.

The Metal and Thermit Corporation, of New York, supply an outfit for making the two welds on the two lines of rails at the same time, the persons on the two lines being [illegible] [illegible] usually opposite one another, as shown in the illustration. The latest [illegible] [illegible] known as the [illegible] [illegible] Weld, [illegible], as shown in Fig. 1,759, a small piece of metal, similar to the metal of the rail, is inserted at the welding head of the rail gap before the mould is built round it. In Fig. 1,759, the [illegible] halves of the two moulds can be seen in the background. The two part mould are then fitted to the rails, as shown in Fig. 1,760, the

[illegible]

joints being luted with asbestos [illegible] [illegible] with [illegible] [illegible] the two halves firmly clamped together by the rectangular [illegible] clamp shown at the side. The outer casing of the mould is of iron, which must, of course, be lined with refractory material of some kind, and much of the success of the process depends upon the choice of this material, for, as already explained, it has to stand a high temperature. Fire clay, or fire clay mixed with clean sand, has been used, and as an alternative a mixture of [illegible] [illegible] and sand in the proportion of 1 to 10 has been recommended, this mixture being [illegible] to a moulding consistency and a little turpentine added where a specially hard mould is required. The next step in the process is a preliminary or preheating of the mould and rail ends, as shown in Fig. 1,761, this preheating also serving the purpose of baking the refractory lining. Meanwhile the crucible containing the thermit mixture has been mounted on a vertical rod clamped to the rail close to the mould and so adjusted that it can be swung into the position over the mould shown in Fig. 1,761. When everything is ready the thermit mixture is ignited [illegible] [illegible] [illegible] [illegible] [illegible], the molten iron being specifically heavier than the alumina sinks to the bottom of the crucible, and at the right moment the plug is knocked out of the hole at the apex of the cone and the molten iron pours into the gate of the mould. The whole is then left to cool, the result being, when the mould is knocked away, that the rails are found welded together by a low carbon steel, for it will be noticed that there is carbon in the material lining the mould sufficient to convert the iron into steel. When the mould is taken away the gate and riser of the weld are seen projecting above the rail, the inserted piece lying between them firmly welded in its proper place. The excresences are ground off and the upper surface made true by a specially designed and electrically driven grinding machine. The final appearance of the weld as seen from one side is as shown in Fig. 1,762. The preheating process referred to, which is a recent development, has made it possible to use a smaller quantity of thermit mixture, and it will be noticed that the superfluous metal on the vertical side of the weld is not excessive.

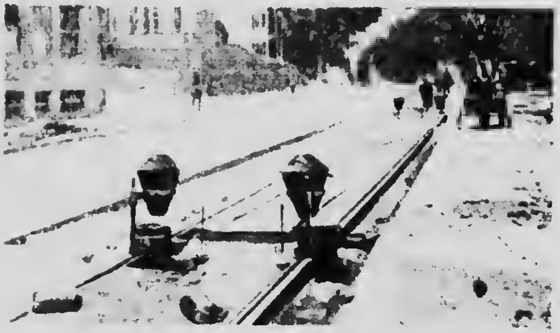


Fig. 1,761.—Preheating the Moulds before Welding

Fig. 1,762.—The Finished Weld.

The result claimed is that the joint has both mechanical strength and electrical conductivity equal to any other part of the rail, that the process is simpler than bonding, and that the face of the rail at the joint, because of the "insert," does not differ from the face on either side. In addition it is claimed that the electrical joint cannot deteriorate with time as bonded joints may, and that mechanically the joint is a "non-shock" joint.

VI. SYSTEMS AND METHODS

The general systems in use for electric traction on railways have been referred to from time to time in the foregoing pages, and the more common methods which have been practically worked out for the supply of energy to the moving train have been particularly described. To enable the reader to grasp the outlines of the modern solutions of the whole problem a further, though necessarily brief, reference is desirable to the chief leading systems which have survived the numerous practical experiments of the past thirty years or more.

The subject, viewed from this broad standpoint, falls naturally into three main divisions :

(i.) The transmission of the energy from the generating station to distributing points or sub-stations conveniently placed along the railway route.

(ii.) The form in which the power is transferred to the moving train.

(iii.) The method of utilisation of the power on the train.

In all three divisions it is necessary to consider the relative merits of the A.C. and C.C. forms of electric power for the practical problems which have to be faced in all their complexity of capital cost, maintenance, over-all efficiency, liability to breakdown, etc. The first division is only of importance on long lines, and for such modern practice is fairly unanimous in the adoption of A.C. power for the transmission to the distributing centres. For short lines no separate transmission is necessary, but as frequently happens in such problems, the limit between long and short lines cannot be accurately laid down. In the other divisions, (ii.) and (iii.) the choice between the two forms is still a matter of somewhat acute controversy, of which we shall presently indicate only the leading features.

Alternate-current Transmission.—The subject of the transmission of electric energy over long distances has been dealt with in detail in Chapter XI. (pages 1100 to 1213), and the merits of the various available systems have been discussed in Section VI. (pages 1184 to 1203) of that chapter. The reasons why three-phase high-voltage, or extra high voltage, systems are used on long railway lines are there set forth, and need not be repeated here; we need only record the fact that such systems are adopted in most cases where the length of the line makes it economical to interpose a sub-station between the generating station and the *distributing conductor*, whether overhead or on the surface, from which the moving train picks up its supply of power.

The Distribution System. When we turn from the transmission to the distribution system, and deal with the form in which the electric power is supplied to the overhead or the surface conductor, we find strong divergencies of opinion amongst practical engineers as to the best system. The choice lies primarily between C.C. and A.C. power, and as regards the latter between single-phase and three-phase systems.

Influence of the Motors. The ultimate choice, however, does not depend entirely or even mainly upon the simple problems of distribution which have been dealt with in the last section (pages 1203 *et seq.*) of Chapter XI., but is largely influenced by the method of utilisation of the power when transferred to the train. Many engineers hold very strongly the opinion that the merits of the series c.c. motor for traction purposes so far exceed those of any of its A.C. competitors that they outweigh all other considerations, and practically decide that the distributing conductor from which the power is picked up shall be supplied with c.c. power. The voltage, however, which can be dealt with by such a motor is low in comparison with that which can be quite safely used on some A.C. motors. It is not so long since 600 volts was not only the standard voltage but was regarded as presenting about the highest voltage at which a satisfactory c.c. traction motor could be designed. The commutator was the chief difficulty, as "flashing over" and other troubles were experienced, but with the development of improved designs, notably in the use of interpoles, these troubles have diminished. In 1907 the line voltage was doubled by placing two such motors permanently in series, but even then each motor had to be able to take 1,200 volts for a short period in certain practical contingencies. Now, however, single motors taking 1,500 volts across the terminals are in operation, and with two of these in series it is possible to raise the c.c. line voltage to 3,000 or higher.

On the other hand, the facility with which A.C. voltage can be lowered by static transformers enables the line voltage in A.C. systems to be independent of any voltage limitations which might be imposed by the particular type of motor used; and moreover there are good serviceable types of A.C. motors which can utilise much higher voltages than the highest yet considered safe for c.c. working. Thus an overhead contact wire voltage of 6,000 is quite common, and higher voltages up to 15,000 have been successfully worked.

On the other hand, the pulsating character of the torque, especially at low frequencies and with single-phase motors, is a source of trouble in A.C. working. It is probably the cause of the track adhesion *at starting* being worse than for a c.c. motor. Thus a single-phase motor has been found to slip with 55 or 60 per cent. of the mean draw-bar pull at which a c.c. motor of the same rating slips.

Continuous-current Working. The net result is that for tramway working and for short railways, and passenger and light traffic, the c.c. system with series motors is almost supreme, the most prevalent voltage at the present time being in the neighbourhood of 600 volts.

It is interesting to note, however, that higher-voltage continuous-current working is making headway, though developments have in this country and in Europe been interfered with by the great war. On the other side of the Atlantic, however, excellent progress has been made. In November, 1916, a list was given in the *General Electric Review*, published in Schenectady, of 17 lines, in various parts of the United States, in which the line voltage varied from 1,200 to 3,000 volts. For the highest voltages two 1,500-volt motors on the locomotives are connected permanently in series. The total track mileage of these lines was then over 3,300 miles, the longest being the Chicago, Milwaukee and St. Paul with a length of 440 miles. It is interesting to note that in nearly every case the transmission system is three-phase, mostly at 60 ~, with voltages up to and exceeding 100,000 volts per phase. All the lines had overhead conductors, which in 23 cases used direct suspension, at 1 in 23 cases catenary suspension, the remaining line using both methods at different sections. With the catenary suspension 13 used sliding or bow collectors, and the remaining 10 trolley wheels, thus showing the influence of standardised practice with lower voltages.

Statistics of so late a date are not, for obvious reasons, obtainable for European systems, but in 1913 *La Lumière Electrique* published a list of 47 high-voltage continuous-current electric railways in Europe. The two earliest of these date back to 1906, one of them using a line current of 1,000 volts, and the other a line current at 2,000 volts, these being the limits of the voltages of all the subsequent railways. The track length is not given in every case, but 44 of the lines had an aggregate length of only 620 miles, the longest being a little over 36 miles.

The links in a modern continuous-current system of electric traction on railways may be conveniently summarised as follows:

(i.) The 3-phase (or single-phase) A.C. generators and switching arrangements in the generating station (*see* Chapter II. and Chapter III., Section v.).

(ii.) The 3-phase (or single-phase) step-up transformers for raising the generator voltage to the transmission value (*see* Chapter VII.).

(iii.) A 3-phase (or single-phase) high-voltage transmission line (*see* Chapter XI.).

(iv.) Sub-stations containing:

(*a*) Three-phase (or single-phase) step-down transformers.

(*b*) Rotary or motor converters (*see* Chapter VIII.).

(v.) An overhead or a third-rail insulated distributing conductor for conveying the energy from the sub-station to the moving train (*see* Sections III. and IV. of this chapter).

(vi.) An electric locomotive or a motor-coach with its picking-up gear, controlling apparatus (*see* Chapter XVII.), and electric motors (*see* Chapter IV., Section VI., and Chapter XVI.).

(vii.) A fourth rail or the track return circuit heavily bonded (*see* Section V., *ante*) with, in some cases, negative feeders and negative boosters.

Alternatively to (iv.) (*b*), (v.) and (vi.) (*first part*), a moderately high A.C. voltage may be conveyed overhead to electric locomotives carrying mercury-arc rectifiers described later (*see* pages 1719 to 1739).

Alternate-current Working.—With A.C. working there is a greater variety of choice than in C.C. working, both in the number of phases which can be employed and in the types of suitable motors available. From the first, railways have been equipped with either single-phase or three-phase systems, whilst more recently split-phase working has been advocated. Choice can also be exercised as to the periodicity adopted, which in actual systems varies as a rule between 25 and 60 cycles per second. An initial disadvantage of three-phase as compared with single-phase working is the necessity of insulating two of the three-phases, and therefore of having two overhead insulated conductors side by side with corresponding complications at turn-outs and cross-overs, and in the devices for picking up the power and leading it into the locomotive or car. Partly on this account three-phase systems have not found favour in this country nor on the American continent, notwithstanding the adoption of three-phase currents for the transmission lines. It is chiefly on the Continent of Europe that practical installations of three-phase working are to be found.

The links in each of the leading A.C. systems may be summarised as follows:

(A). *Three-phase system.*

(i.), (ii.) and (iii.) as set forth on page 1591 for the continuous current system.

(iv.) Sub-stations containing three-phase (or groups of three single-phase) step-down transformers.

(v.) Two overhead distributing wires insulated from the earth and from one another (*see* pages 1548 to 1558, and Figs. 1,644 1,645 and 1,709, *ante*).

(vi.) An electric locomotive or a motor-coach with its picking-up gear, controlling apparatus (*see* Chapter XVII), and 3-phase electric motors (*see* page 1614, *infra*).

(vii). A track return properly bonded (*see* Section v., *ante*), and, where necessary, with sectional inductive devices to diminish the voltage drop.

(B). *Single-phase system.*

(i.), (ii.) and (iii.) as set forth on page 1591 for the continuous-current system, or

(ii.') Single-phase step-up transformers for raising the generator voltage to the transmission value.

(iii.') A two-wire single-phase high-voltage transmission line.

(iv.) Sub-stations containing either

(*a*) Three-phase step-down transformers and three-phase to single-phase phase changers (*see* page 948) or

(*a'*) Single-phase step-down transformers

(v.) A single overhead distributing conductor (vi.) An electric locomotive or a motor-coach with its picking-up gear, controlling apparatus (*see* Chapter XVII.), and single-phase electric motors (*see* Chapter XVI.)

(vii.) As set forth in A (vii.) above.

Under both (A) and (B) the voltage on the overhead conductor may be raised much higher than in C.C. working, and if too high for the motors a step-down transformer on the locomotive does not occupy much space, and is easily manipulated. Moreover, such a transformer sometimes is an essential part of the controlling apparatus described later (*see* Chapter XVII.).

The controversy as to which is the best system as a practical proposition has mainly ranged over the comparative merits and demerits of continuous-current working and of single-phase A.C. working. The final test in each case is, of course, the total cost per unit of remunerative traffic, taking account of all the items, including interest on capital employed, running charges, maintenance and depreciation, administration charges, etc., etc., together with reliability of service, which includes ease of manipulation and convenient handling of the traffic. Masses of comparative statistics derived from actual systems have been published by the advocates on each side, and their lessons enforced by numerous diagrams and curves. With these we do not propose to try the patience of our readers, but simply record our opinion that for general purposes the high-voltage C.C. system appears to come out best in the controversy. Both sides, however, are agreed that the "steam locomotive," to quote one well-known authority, "has reached its limitations, and has been found unsuitable and inadequate in tunnels or in terminal service."

Actual Railways. The various details of the different systems referred to in this section are fully described and illustrated in other parts of the book, to which references are given, and therefore only some general details of one or two typical systems of each kind need detain us here. The examples chosen have their characteristic details well illustrated elsewhere.

Continuous-current Railways.—Early electric railways operated by continuous currents have already been described in a special section (*see* pages 1514 to 1522, *ante*), in which particulars are given of the City and South London, the Liverpool Overhead, and the Manhattan Elevated Railways. Sufficient reference has also been made on pages 1524 to 1527 to the more modern Tube Railways which form so striking a feature in the facilities for intra urban travelling in London, especially on the north side of the Thames.

Following on these a notable development was the electrification of the Liverpool and Southport section of the Lancashire and Yorkshire

Railway, and then came the electrification of other suburban lines in different parts of the country. It would probably be considered but wearisome repetition were we to describe here the main features of each of these, for the typical essential details are referred to in other sections of the book. As a fairly recent example we confine ourselves to the chief details of the electrification of the Manchester and Bury section of the Lancashire and Yorkshire Railway.

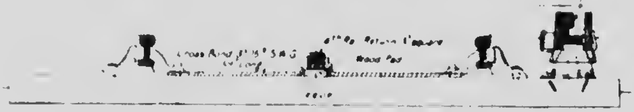


Fig. 1,763.—Cross-section of Permanent Way, Lancashire and Yorkshire Railway.

This section is essentially a suburban section, and is shorter than the Liverpool and Southport section of the same railway company. It connects the city of Manchester with the town of Bury, the total length of single track electrified being 22 miles. The chief technical development is the raising of the C.C. voltage from 600 volts to 1,200 volts, the distributing conductor being a third rail with bonded track rails augmented by a return or fourth rail, electrically connected to the track rails for the return circuit, but not arranged to make connection with any rubbing contact on the train. This fourth rail is of slightly larger cross-section than the insulated third rail, and weighs 88·5 lb. per yard as against 85 lb. per yard, the weight of the insulated rail; the shapes of the cross-sections are quite different. Details of the two conductors and the two track rails are given in Fig. 1,763, which also shows their relative positions. The mounting of the insulated rail is described elsewhere (*see* page 1536); the fourth rail simply rests on wooden pads secured to the sleepers by iron dogs, and is anchored at intervals of 100 yards. The flexible bonds connecting it electrically to the track rails are clearly shown in the figure. A diagrammatic plan of the permanent way in relation to the structure and load gauges is given in

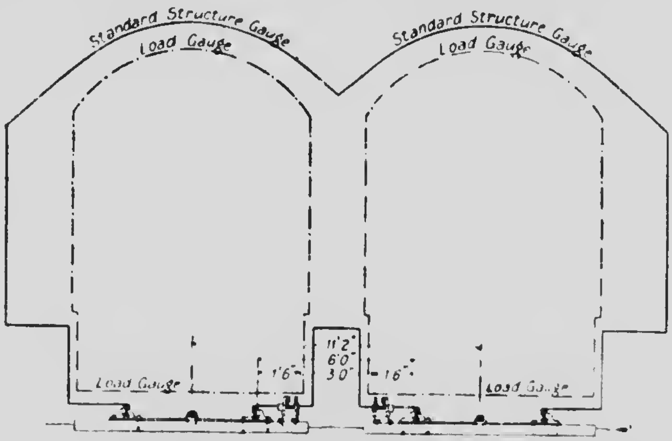


Fig. 1,764.—Cross-section of Permanent Way in relation to the Structure and Load Gauge, Lancashire and Yorkshire Railway.

Fig. 1,764, in the lower part of which the relative positions of the track and conductor rails are clearly shown. The insulated third rail for both the "up" and the "down" tracks is placed in the six foot, its outermost fitting being 18 inches from the nearest track rail, thus leaving 3 feet clear in the six foot for other purposes. The appearance of the track between stations is shown in Fig. 1,765. Here the position of the insulated third rail is clearly seen, with some interesting additional details consequent upon the photograph having been taken near a cross-over from the right to the left-hand track, the left-hand end of this cross-over being shown in the foreground. The cross-over, it will be observed, has necessitated the interruption of the run of the insulated conductors in the six-foot, and the laying down instead of short lengths outside the outer rails on each side, there being, of course, a certain amount of overlap of the corresponding conductors on either side of each single track. This is clearly shown in the figure, which also shows the bending inwards of the insulated conductor at the interruption to ensure that the side-running brush on the train shall pick up the conductor without mechanical shock. This side-running brush is also another technical feature of this particular railway; it will be found described in detail on pages 1536 and 1539.

Fig. 1,765. The Track between Stations on the Lancashire and Yorkshire Railway.

A train consisting of motor-coaches and trailers is shown in Fig. 1,766. As already mentioned the line voltage is 1,200, and special precautions are taken to prevent accidents to employees. All the 1,200-volt equipment on the motor-coach is housed in a special chamber, the door of which is interlocked so that the isolating switch connecting the control leads from the rubbing contacts must be opened before anyone can obtain access to the chamber. The multiple-unit control system described later is used, and is operated by a 100 volt current which is obtained from the 1,200-volt circuit through a rotary transformer mounted under the motor coach. The current for lighting and for the pump motor of the vacuum brake are also taken from the 100-volt circuit.

Single-phase Railways. Single-phase working on railways reaches probably nearly as far back as continuous-current working, and we describe elsewhere many of the details of the machinery and apparatus employed. We do not propose to describe in detail here the large number of railways which have been so equipped, but shall be content with a few additional references to the typical single-phase line in London, which was electrified some ten years since.

The first application of single-phase alternate-current working to railway traction in London was made early in this century by the London,

Fig. 1,7[illegible].—Motor-coach and Trailers, Lancashire and Yorkshire Railway.

Brighton and South Coast Railway Company in the electrification of its suburban steam line between London Bridge and Victoria, a line which had long been an important section in the railway accommodation of South London. The first contract for the electrification was placed in 1906, and the section referred to was opened for electric service in December, 1909, the whole of the electric construction having been carried out without interference with the steam service. The section thus dealt with was 8·7 miles long, and altogether 20·5 miles of single line were provided with electric equipment. The success, from a traffic point of view, was practically immediate, so much so that in the following May it was decided to equip as quickly as possible other adjacent routes, bringing the length of electrified single line up to 62 miles. Following on the success of the Liverpool and Southport section of the Lancashire and Yorkshire Railway system (*see* page 1593), opened as an electric line in 1904, the advantages of electric working as against steam working for suburban lines in large towns were thus abundantly demonstrated.

The London, Brighton and South Coast Railway engineers, in planning the scheme of electrification, had to consider the possibility of the electric equipment being extended to the whole of the main line between London and Brighton, a distance of 50 miles, and it is understood that it was this which mainly led them to adopt the A.C. single-phase overhead system with a pressure of 6,700 volts on the line. With this voltage, as had for some time been common practice on the Continent, overhead conductors were considered preferable to rails laid on the surface of the ground, and the catenary system, with bow collectors (*see* page 1540 and elsewhere), was decided upon. The trains are made up of motor coaches and trailers, the English side-door system so conducive to rapid handling of suburban traffic being adopted in lieu of the American corridor and end-door system so common on electric railways. In the first equipment each motor coach was equipped with four motors, each capable of giving 57 B.H.P. continuously, or 115 H.P. for one hour with a rise of temperature of 75° C. In later equipment the motors were larger, and could give 100 H.P. continuously or 175 H.P. for one hour. With the larger motors, one motor coach could handle two trailers, and in slack periods of the traffic three such coaches made up a train, which was doubled when the traffic became heavier.

Details of the motors and of the control system and the coach wiring are given elsewhere (*see* pages 1692 to 1694), but it may be noted here that the weight of an empty three-coach train is 102 tons, including all motors and electrical equipment. The energy consumption during the first eight months of working was 75·4 watt-hours per ton-mile of paying traffic, no deduction being made for empty running and shunting or for leakage, and no allowance for the weight of the passengers. The distribution losses from the sub-stations at which the energy was purchased from the London Electric Supply Corporation was about 3 per cent.

The effect of the change to electric driving in this case is an excellent example of the financial advantages to be obtained. For some years, in competition with the electric tramways of the district, the railway company working with steam locomotives had been losing its suburban passenger traffic, until the loss had reached 5,000,000 passengers per annum. In the first twelve months of electric working, with very little alteration in the fares, the whole of this traffic was recovered.

Various details of the equipment of other single-phase railways have been given in Section IV., *ante*. These include the methods of erecting the overhead conductors, details of the current collectors, and views of the tracks. Details of the motors, locomotives, control and other apparatus appear later. In this section it is unnecessary to carry the descriptions further.

Three-phase Railways. The tracks and overhead conductors of three-phase railways have been illustrated in Figs. 1,694 and 1,695. The three-phase method of working is favoured on the continent of Europe, especially for the electrification of mountain railways. Some of its advantages and disadvantages have already been pointed out, and other comparisons are made later when describing other items of equipment. The outstanding disadvantage of three-phase motors for traction work is their limited range of speed (see page 742) which is only partly extended by the tandem or cascade methods of working described in Chapter V. (see pages 740 *et seq.*). One valuable feature of a three-phase traction system is the automatic action of the motors in acting as generators, returning energy to the supply circuit whenever the speed exceeds synchronous speed by a few per cent. When so acting they absorb energy from the moving train, which is thus automatically braked, and this makes it impossible for the train to race on a down grade. This braking comes in quite gradually, and in practice it has been found possible to allow a higher speed down grade with this automatic electric braking than with ordinary mechanical braking.

CHAPTER XVI

TRACTION MOTORS AND LOCOMOTIVES

IN the two preceding chapters we have dealt, with as much detail as space permits, with the equipment designed for supplying electric energy to moving tramcars and road vehicles and to moving railway trains. It now becomes necessary to refer to the machinery for utilising and controlling the energy so supplied, leaving the results, costs, etc., to be dealt with later.

The most important item of such machinery is obviously the traction motor or motors, whose function it is to transform the electric power received from the supply conductors into the mechanical power required to propel the vehicle or train. Descriptions of many types of both c.c. and A.C. motors have appeared in the preceding pages, and the principles underlying their design and construction, together with details of typical machines showing the application of these principles, have been given. Amongst these are included (*see* pages 622 to 641) the c.c. traction motors developed for tramcar service, which, in their heavier forms, are available for light railway work.

Before supplementing these descriptions with a few particulars of motors specially designed for railway purposes, there is a preliminary question which is worthy of brief consideration, namely, whether the transformation of the power from the electric to the mechanical form should be concentrated in one vehicle, the locomotive, or whether the transforming motors should be distributed in convenient positions along the train. In the former case, at least for heavy traffic, the individual motors must be of large power, and therefore proportionately heavy, whilst in the latter the size of the individual motors will depend upon the amount of subdivision of the driving power which experience shows to be possible and desirable.

I.—LOCOMOTIVES *v.* DISTRIBUTED MOTORS

The last point touched upon, namely, the size of the individual motors, brings in its train some purely electrical considerations. With large high-powered motors at low voltages, say 600 volts, the currents which have to be handled by the switching and controlling apparatus will be heavy currents mounting into thousands of amperes. The handling of such large currents at the contacts of the controller almost inevitably requires that all the motors and the controller should be on the same vehicle, which becomes the locomotive, even though in some part of it passengers may also be carried. The rest of the train will then consist of trailer carriages or trucks, only because the passage of large currents along the whole length of the train would necessitate the provision of heavy conductors, which would increase the first cost and the maintenance charges, and would, moreover, give rise to difficulties at the couplings. For heavy trains hauled by a single locomotive, the latter must also be heavy, not only on account of the weight of the large motors required to do the work, but also because the necessary adhesion between the smooth-tyred driving-wheel and the smooth rail can only be obtained by large pressures at the contact surfaces.

Heavy locomotives, however, labour under serious disadvantages. In the first place they require that the permanent way, including all bridges, etc., should be more substantially constructed than if the heaviest vehicle to be carried were much lighter. Moreover, at high speed the evils of vibration are much more pronounced, and cases have been known where injunctions to ensure the abatement of the nuisance caused thereby to inhabitants close to the route have been obtained in the law courts. Such vibrations also shorten the life of the track, and make the upkeep much more costly.

The employment of separate locomotives is most advantageous, if not absolutely essential, for heavy mineral and goods traffic, and is necessary for shunting operations and also for lighter traffic on lines which are not entirely electric but on which steam power is still used. In all these cases the ordinary rolling stock for either passenger or goods traffic can still be used, the electric locomotive simply taking the place of the steam locomotive as a self-contained tractor, and not requiring a specially constructed train.

But the most important objection to electric locomotives, at any rate for suburban traffic, is that they sacrifice one of the greatest advantages of the electric drive as compared with the steam drive, namely, *rapid acceleration*. With steam driving, it is practically necessary to generate all the driving power in a single vehicle, which in modern locomotives has become a marvel of mechanical design and massiveness. But with electric driving it is otherwise, and it is obviously possible, if deemed desirable, to apply an electric motor to every running axle on a long train. In this way every wheel becomes a driving wheel and adds its mechanical effort to that of the others, thus enabling, during periods of acceleration, full speed to be reached much more quickly than when the whole driving energy has to be dealt with by four, six, or eight wheels only. For suburban traffic, with stopping stations close together, this rapidity of acceleration is very desirable, and adds to the facilities of the service. It is not necessary for long-distance express traffic, where there are long non-stop runs, and for such traffic the heavy and powerful locomotive offers practical advantages. But with short-distance suburban traffic it is otherwise, and schedule time from terminus to terminus can be materially shortened by using distributed motors. The train, however, must obviously be controlled by a single driver, who must also necessarily be in the leading vehicle, and it is because of this condition that the large current difficulty above referred to presents itself, and some way has to be found for supplying current to a number of motors placed on different vehicles other than by bringing all the power currents to a single controller. Some of the methods by which this problem has been solved are described in Chapter XVII., *infra*.

With this preamble we propose now to deal with the developments for railway service of the C.C. and A.C. motors already described, whether for use as distributed motors or as employed on locomotives, in which cases we shall for convenience, include descriptions, so far as we propose to develop them, of the actual locomotives.

II. CONTINUOUS-CURRENT TRAIN MOTORS

The principles and details of the construction of the modern continuous-current tramcar motor have already been dealt with very fully in Section I. of Vol. II. (*see* pages 622 to 641), and therefore it is not necessary to deal with the railway motor with the same fullness of detail.

Two classes of cases arise: the first, in which there being some system of multiple-unit control, relatively numerous motors are distributed throughout the whole length of the train, in which case the individual motors need not differ much from high-powered tramcar motors. In the other case the driving motors are collected in a separate locomotive, and are fewer in number; they are consequently larger and higher-powered motors, though they may still and often do follow the general design of the tramcar motor, one difference being, however, that the armature may be built up on the driving axle and gearing dispensed with.

Such locomotives, driven by two bipolar motors with their armatures built up on the running axles, were used on the first electric railway, the City and South London Railway, opened in 1890, and these motors have been already described (*see* page 1516). They were very similar to motors designed for other purposes at or about that date. The gearless motors used in 1893 on the Liverpool Overhead Railway have also been illustrated in Fig. 1,648 (page 1520). Later, when the Central London Railway was opened in 1900, the motors—of which there were four on the locomotive—resembled tramcar motors more closely, but were larger, 175 H.P. each, and were also gearless.

Gearless v. Geared Motors.—The relative advantages of gearless and geared motors for electric traction have, as regards tramway service, been briefly referred to on page 637, and for such service geared motors with single-reduction gear are now almost exclusively used. For railway service, however, the possibility, and in some cases, the necessity, of collecting the driving motors on a locomotive, as already discussed on page 1600, completely alters the outlook, and it is interesting to note that high-powered single-reduction motors of tramway type are used for railway purposes even when the geared shaft is not a running axle of the locomotive.

The introduction of reduction gearing of course entails additional frictional losses, although it offers certain countervailing advantages. The effect on the efficiency in the case of the motors on the North Eastern Railway locomotive described on p. 1565, is shown in the various curves in Fig. 1,767. Without the gears the motors have a maximum efficiency of about 93 per cent. which, with the gears included, falls to about 87·5 per cent. These curves give a measure of the price which has to be paid for the advantages obtained in other directions.

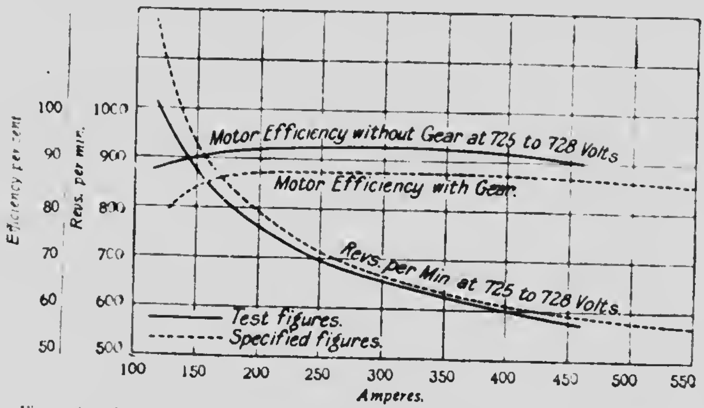


Fig. 1,767.—Performance Curves of Single-reduction Motor, with and without Gears.

When the motors are "distributed" to drive the running axles of motor coaches with or without trailers interspersed throughout the train, the requirements are much the same as for tramway service, except that higher maximum speeds and higher powers are required. The arguments for single-reduction gearing are similar to those already set forth.

Where, however, the exigencies of the traffic or other considerations require the use of locomotives, gearless motors may be employed. With any such form of direct drive, however, it is obvious that low-speed motors must be used and this may involve excessive first cost for, as we have shown at page 602, such machines are relatively larger and heavier for the same output than geared machines running at higher speeds. Where a motor drives only one pair of driving wheels, economy of first cost would therefore lead to geared motors being adopted. The introduction of side rods and coupled driving wheels, so that one motor can drive several pairs of wheels makes it possible to use large motors without using so much power on one pair of wheels as to cause serious "slip." These motors can quite well be low-speed motors running at the same speed as the coupled driving wheels which they are required to drive, and yet of so large an output that their first cost per unit of power is less than the cost of the "distributed" motors necessary for the same driving power.

Fig. 1,768.—Field Magnets of a Central London Railway Motor [illegible]

As with single-reduction gearing there is, of course, a loss of power to be borne in the use of the mechanisms employed in a side-rod drive. Some of the data exhibiting the loss in one or two typical cases are given later in connection with the descriptions of those cases.

Without pursuing the arguments further, we shall now describe one or two motors of both the geared and the gearless type, commencing with the gearless motors used on the locomotives of the Central London Railway when it was first opened.

The field magnets of one of these motors are illustrated in Fig. 1,768 and will be observed to be similar in design to tramcar motors, one difference, however, being that the axial length of the pole face is relatively much greater. The motor had four poles, the axes of which were horizontal and vertical instead of being along the 45° diameters. This is shown more clearly in Figs. 1,769 and 1,770, in which it will be further noticed that the field frame is unequally divided for opening-up purposes along a plane inclined to the horizontal which clears the pole cores. These sketches are

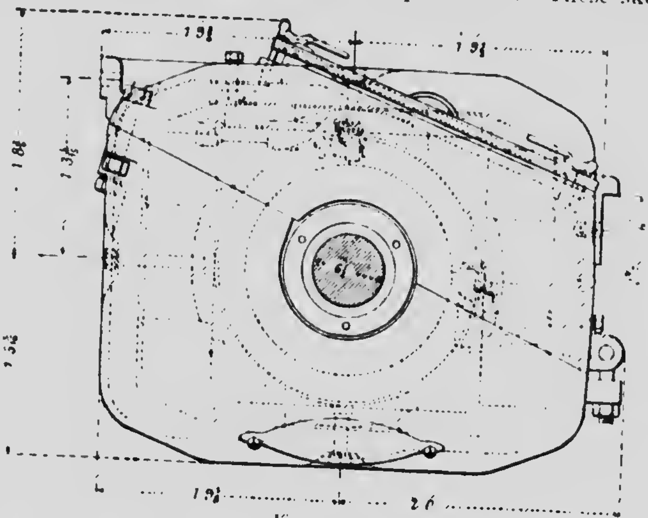


Fig. 1,769.

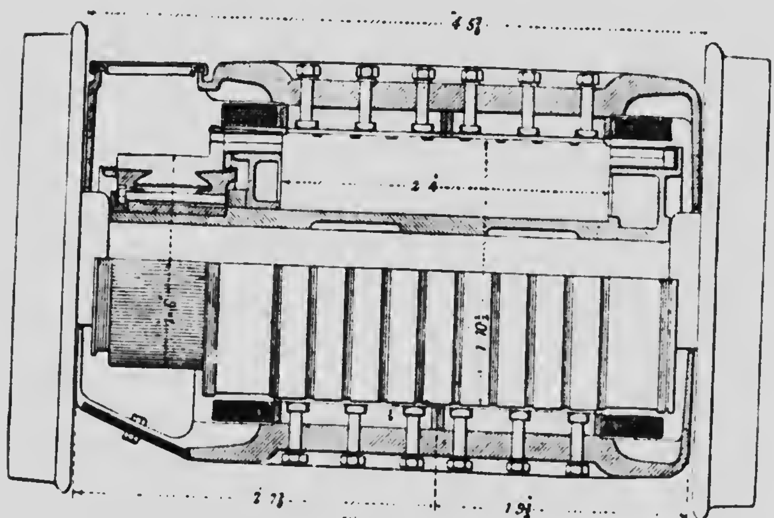


Fig. 1,770.
End Elevation and Section of Central London Railway Motor.

dimensioned, and the sizes given should be compared with the corresponding sizes previously given of tramcar motors.

The armature of the motor is shown *in situ* on the running axle in

Fig. 1771 which represents a portion of the truck upon which the locomotive is carried. Longitudinal sections of the machine, giving further details of the magnetic circuit and details of the commutator, are given in Fig. 177[illegible], in which also the principal dimensions are marked. The tyres of the wheels are also shown in that figure, and attention is called to the way in which practically the last inch allowed by the standard gauge has been utilised by the designer.

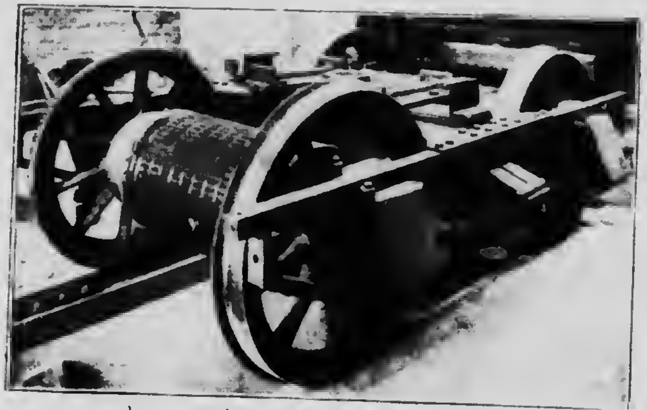


Fig. [illegible] Armature of Motor [illegible]

It may be noted that the diameter of the armature is 22½ inches and the length of the armature core 28 inches; also that the commutator is very massive, and has a diameter of 18 inches, being only 4½ inches smaller than the armature, making it [illegible] to slip the armature into short lugs from commutator. The excitation coils are shallow and compact, and other interesting details can readily be made out. The armature without the axle weighed 3,000 lb. and the complete motor 12,000 lb.

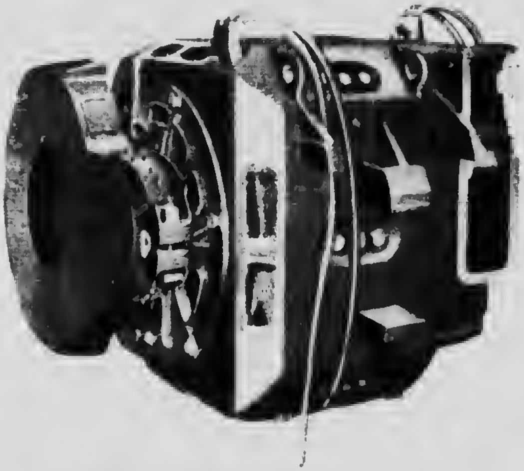


Fig. [illegible] [illegible] Motor [illegible] Chicago, Milwaukee and St. Paul Railway.

Particulars of the locomotives on which these motors were used are given on page 1615.

We pass from this example of what is now a somewhat historical gearless motor to describe a more recent type of geared motor, referring the reader for intermediate examples to the descriptions of traction motors given in Chapter V. (pages 622 to 641). As an excellent example we select one of the 1,500-volt, 400 to 450-H.P. motors designed by the General

Electric Company, of Schenectady, for the Chicago, Milwaukee and St. Paul Railway, and used to equip the heaviest and largest electric locomotives which had been built up to 1918.

An external view of this motor is given in Fig. 1,772, and line drawings of an end view and a plan with the principal dimensions marked on them are given in Figs. 1,773 and 1,774 respectively. It will be noticed that the motor has double gears, one at each end of the armature axle, from which the power is therefore delivered at both ends. In this it differs from the lower-powered tramcar motors, and the mechanical advantage in dealing thus with high powers is obvious. Like all traction motors which have to work between the driving wheels on the ordinary English gauge of 4 feet 8½ inches, the design is very compact axially, and all the available space is well utilised. Nevertheless, it has been found possible to assign 20 inches of this length to the two armature-bearing surfaces which are each 10 inches long and 5¾ inches in diameter. As the machine is to be mounted on a locomotive, vertical space is not of so much importance, and a little extra room has been obtained by raising the level of the armature axle a little above that of the running axle. This device has also certain mechanical advantages in the distribution of the various forces called into play when running.

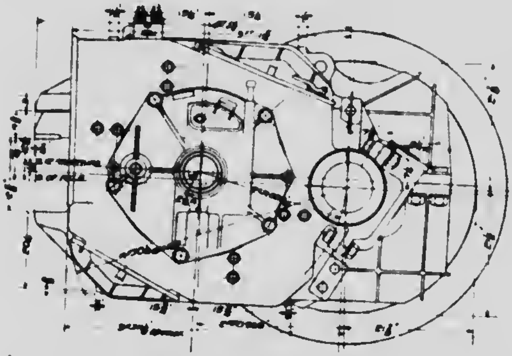


Fig. 1,773.—End View of Double-geared Single-reduction Motor.

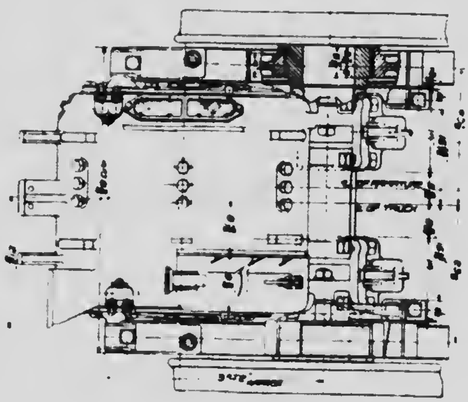


Fig. 1,774.—Plan of the Motor

The field magnets, which are shown wound in Fig. 1,775, are of the box-frame type, with four main poles and four commutating poles. The motor is wound for shunted field control, the fields being shunted 50 per cent. in motoring at full speed.

These motors are rated to give 452 H.P. for one hour, with a temperature rise of 100 degrees Centigrade in the copper of the armature as measured by its resistance, and with 120 degrees Centigrade rise in the field coils.

For continuous running the power developed with the same temperature limits is 300 H.P. To withstand these temperatures, which are much higher than those allowed in the motors previously described, the field coils are insulated with asbestos and mica, the copper being in the form of flat strip.

A transverse section of the motor is given in Fig. 1,776, and a longitudinal section in Fig. 1,777, and from these the most important details can be made out, the dimensions being ascertainable approximately from the scale at the side. The commutator, which has to handle 1,500 volts, consists of 343 segments connected to the same number of single-turn coils lying in groups of 7 in 49 armature slots, the diameter of the armature core being $20\frac{1}{2}$ inches. The slots are thus few in number and correspondingly large, the distance from centre to centre of adjacent slots being 1·9 inches. To withstand the high

Fig. 1,775.—Field Magnets of Double-geared Railway Motor

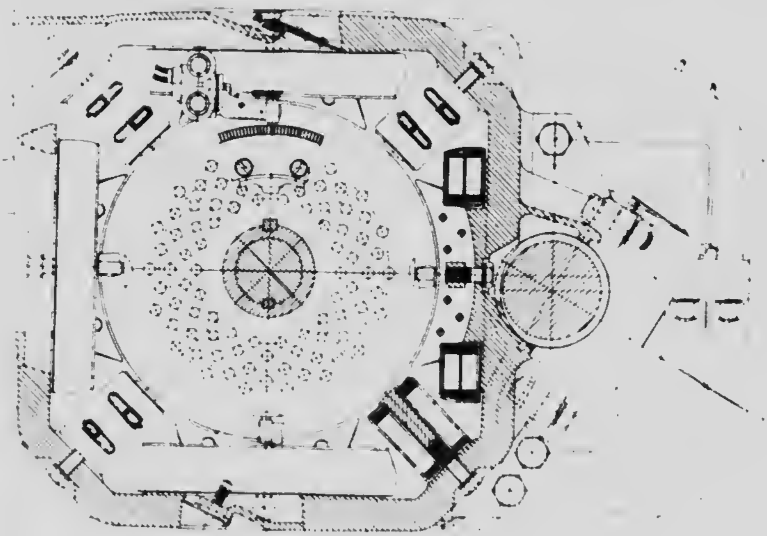


Fig. 1,776.—Transverse Section of Double-geared Railway Motor temperatures mentioned above the armature coils are also insulated with mica and asbestos, and when developing 452 H.P. at the one-hour rating the armature runs at 416 revolutions per minute. There are four brush holders on the motor: two of them, fixed on the main poles, can be seen in Fig. 1,776. The commutation is excellent when it is remembered that the voltage is 1,500 per motor. In fact, on a stand test, 2,250 volts, being 50 per cent. above normal, has been used without injurious sparking. The armature core and the corehead carrying the commutator are mounted on a central spider, and large openings are provided in all of them to secure effective ventilation. A ventilation blast is supplied by an external blower, and the volume of air used to keep the motor cool at the continuous rating is 2,500 cubic feet per minute; this air enters through the large opening at the front of the magnet, which can be seen in both Figs. 1,772 and 1,775.

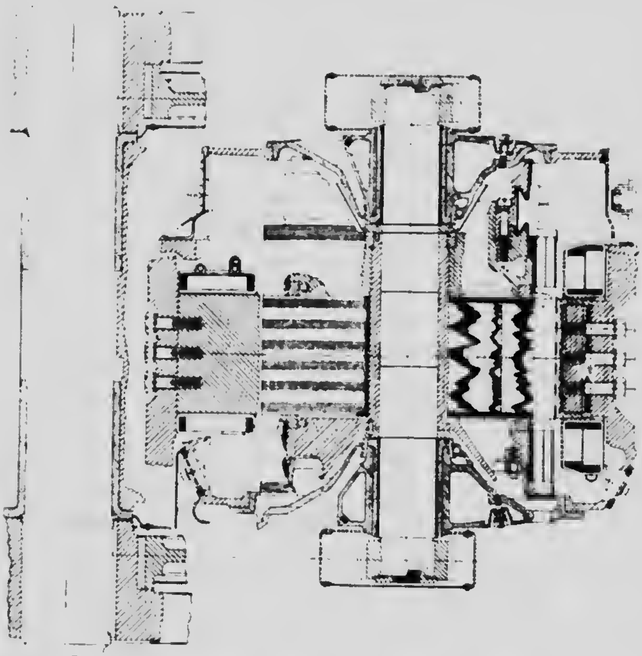


Fig. 1,777.—Longitudinal Section of Double-geared Railway Motor.

In transmitting these high powers from the armature shaft to the driving wheels under the severe conditions of railway service, interesting mechanical problems present themselves. One of these arises from the inelasticity of toothed gearing as compared with a belt drive when sudden shocks or "hammer" blows, so frequent in rail work, are delivered on the driving wheels, the problem being to prevent these damaging the gear teeth. To solve this problem an elastic or "cushioning" connection is interposed between the driving-wheel axle and the gear wheel, the solution adopted being the spring gear shown in Figs. 1,778 and 1,779. The first figure shows the complete gear with the slotted collar to which the driving axle is to be keyed. The details are shown separately on a smaller scale in Fig. 1,779. The collar keyed to the axle is the hub of a six-armed spider with radial projections on the inside of the gear wheel. Between the arms and the projections coiled springs are interposed, and form elastic buffers mechanically placed between the shaft and the gear wheel. It may be recorded that on passenger locomotives the gear ratio is 29 teeth in the pinion and 71 in the gear, and for freight locomotives the corresponding figures are 18 and 82;

Fig. 1,778.—Spring Gear.

Fig. 1,779.—Spring Gear Details.

the speed reduction is therefore 2·45 to 1 in the first case and 4·5 to 1 in the second case.

Cushion Gearing.—As elastic or "cushion" gearing has now been mentioned, it is of interest to inquire whether the use of such gearing in ordinary working leads to any saving of the energy supplied to the motors, in addition to the advantage it has of absorbing the shocks, thus making

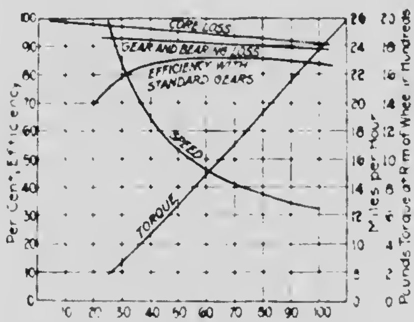


Fig. 1,780.—Motor with Standard Gear.

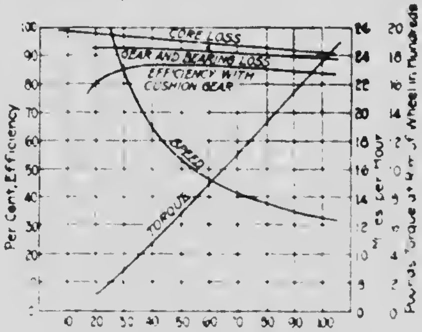


Fig. 1,781.—Motor with Cushion Gear.

passenger trains more comfortable for travellers, and also, it is to be presumed, decreasing the cost of repairs and renewals of the motors and the vehicles on which it is used.

The inquiry can only be answered by experiment, and we give, as a contribution to the discussion, in Figs. 1,780 and 1,781, characteristic curves of two similar railway motors, one (Fig. 1,780) with the ordinary standard gear, and the other (Fig. 1,781) with cushion gear. It will be noticed that the efficiency curve has a maximum slightly higher in the latter case, and that it is considerably higher at the higher speeds. Applying the data given to a 20-ton car making seven stops per mile with a schedule speed of 10·7 miles per hour, a saving of 13·5 per cent. is shown. For such a type of service, therefore, a 10 per cent. saving or more may be reasonably anticipated. For long-distance working with fewer stops the saving might be less, though this could only be determined by actual running experiments with two precisely similar trains with and without cushion gears respectively, because a great part of the extra loss is caused by the vibration due to gear teeth, which affects the whole of the working parts of the motor, especially when the teeth and the bearing linings become worn. The curves given in Figs. 1,780 and 1,781 are for new 600-volt C.C. motors in good condition.

The point is an important one, and the experiments suggested are costly, but if the saving be anything approaching the amount indicated above they are well worth making if this has not already been done.

III.—Alternate-current Train Motors

In Chapter V. on "Alternate-current Motors," a special section (VI.) (pages 800 *et seq.*) has been devoted to "*Monophase Commutator Traction Motors.*" In this section there will be found detailed descriptions of (i.) the Westinghouse Motor (page 801), (ii.) the Winter-Eichberg Motor (page 805), used on the South London section of the London, Brighton and South Coast Railway, and (iii.) the Oerlikon Motor (page 807), used on the Lötschberg Railway in a mountainous district in Switzerland. All these were specially designed for railway service, are operated by high-voltage, single-phase currents, and are representative examples of the A.C. motors which have been designed for, and have been successful in, single-phase working. Some of the locomotives on which these motors are mounted are described in the next section, and the controllers for operating them are described in the next chapter. It would therefore seem unnecessary to describe here any additional examples of this type of traction motor.

Three-phase Induction Motors.—The drawback of this type of motor for general railway work, as mentioned elsewhere, is the inflexibility of its speed as compared with commutator motors. It is, however, possible with two motors, and by changing the number of poles (a speed-changing device also referred to elsewhere) to obtain as many as four economical running speeds. Such devices are employed on the Italian State Railways, and details of one of the motors used will be interesting.

As an example we take the motor used on the high-speed three-phase locomotives supplied to the Italian State Railways by Messrs. Brown, Boveri & Co., and built at their Milan works. A longitudinal section of this motor, taken from *The Electrician* of June 1917, is given in Fig. 1782.

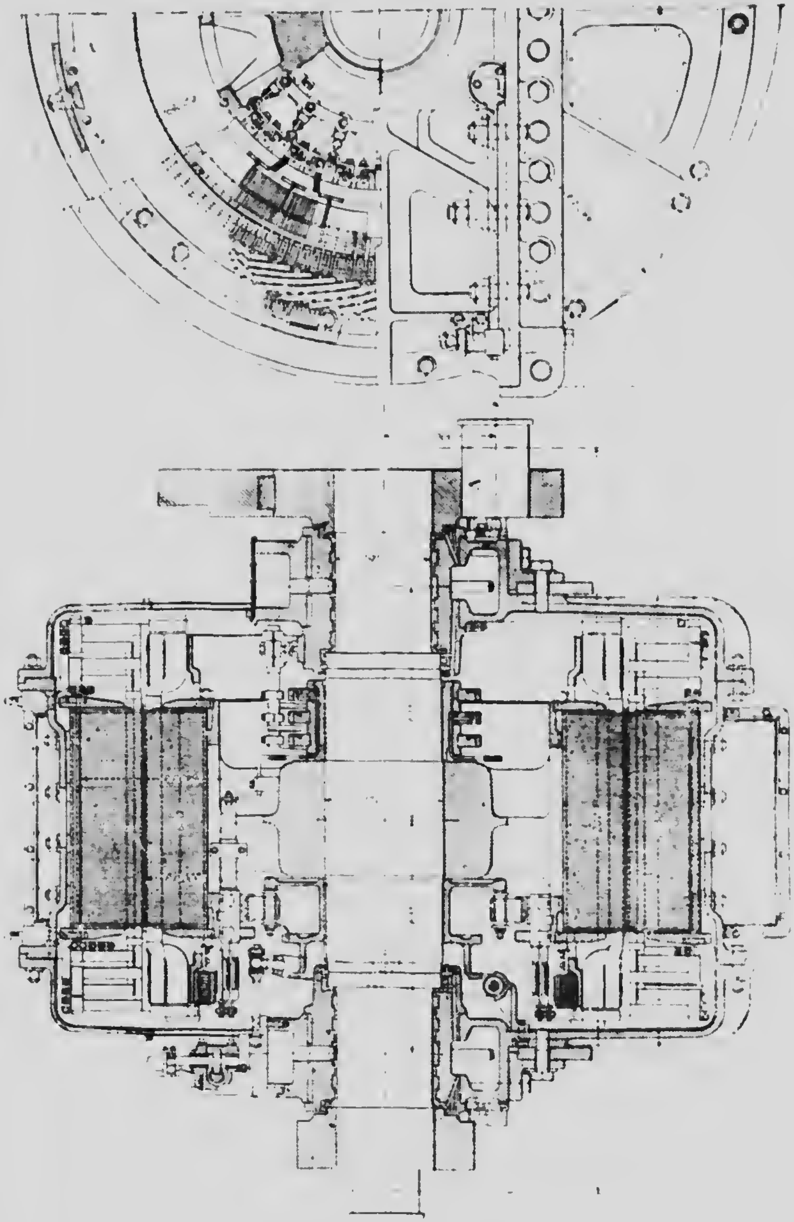


Fig. [illegible]

and a transverse half-section in Fig. 1,783. A pair of these motors can be operated, if the supply frequency be 16·7 periods per second, so as to run the train at 100, 75, 50 or 37·5 kilometres per hour. At the two highest speed the efficiency is 93·5 per cent. and the power factor 0·85. The speeds mentioned were carefully selected so as to give the best over-all efficiency (including the losses in the controlling apparatus) for the different types of traffic, both express and stopping, and on heavy and light gradients. This increased efficiency is held to justify the extra complications in the switching equipment.

It will be both instructive and interesting for the student to compare the details shown in Figs. 1,782 and 1,783 with the similar details of the polyphase induction motors described in Chapter V. (*see* pages 660 to 765). Special attention may be directed in this connection to Figs. 690, 704 and 705, and to Plate XII. (page 692). In any such comparisons the outputs of the various motors and the electrical conditions must be kept in view. The motors now illustrated are designed to work on a three-phase supply at 3,000 to 3,700 volts, and a frequency between 15 and 17 periods per second. The output of two motors when running at top speed is 2,200 H.P., and 2,500 H.P. at the second speed, both measured at the periphery of the driving wheels. The B.H.P. on the motor shaft is obviously still higher, and the machines are therefore much higher-powered than any previously illustrated.

The more interesting chief dimensions are marked in millimetres on the figures, and many details are shown to which we need not refer, as similar details have been fully described elsewhere. Attention may, however, be called to the fact that axial length is reduced by placing the slip-rings of the rotor almost completely inside the cylinder formed by the core of the rotor; also neither this core nor the core of the stator has any radial ventilating ducts. The shaft is massive, being 260 mm. (10·2 in.) where it passes through the bearings, and the diameter of the wound rotor is 1,300 mm. (51·1 in.). The power is transmitted to the driving wheels, of which there are three pairs coupled by inclined connecting rods attached to A (Fig. 1,782) and two intermediate shafts, to which further reference will be made later if space permits.

The methods of varying the speeds of induction motors with wound rotors by varying the polarity of the stator and working two motors in combination have been explained in Chapter V. (*see* pages 747 to 751). In this case the four synchronous speeds are obtained by the following arrangements:

23 miles per hour with motors in cascade, each stator having 8 poles (Fig. 1,784).
31 „ „ „ „ „ „ 6 „ (Fig. 1,785).
47 „ „ „ parallel, „ „ 8 „ (Fig. 1,786).
62 „ „ „ „ „ „ 6 „ (Fig. 1,787).

The diagrams in Figs. 1,784 to 1,787 give connections for the four cases, with separate explanatory diagrams at the side showing the internal connections of the stators of the "primary" and the "secondary" motors respectively.

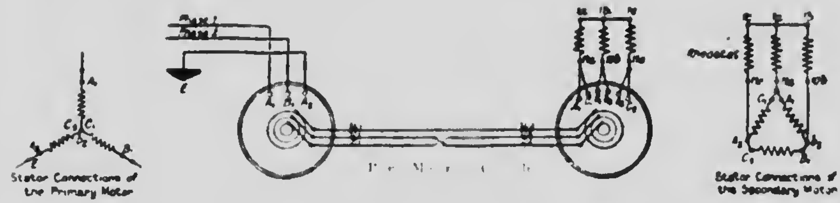


Fig. 1,784.

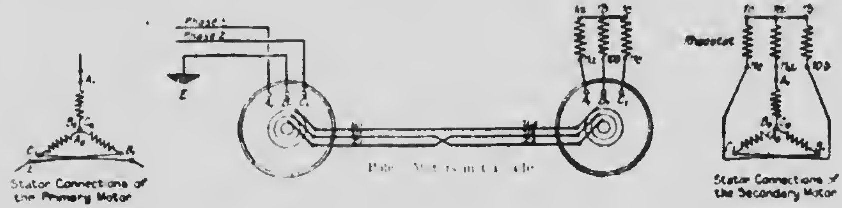


Fig. 1,785.

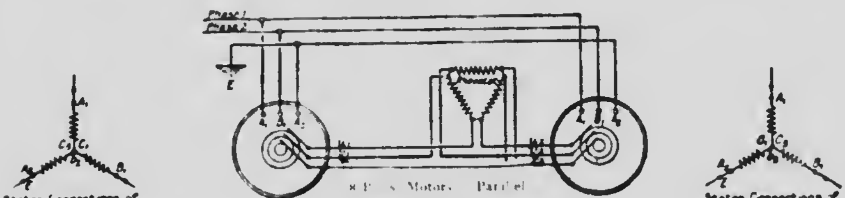


Fig. 1,786.

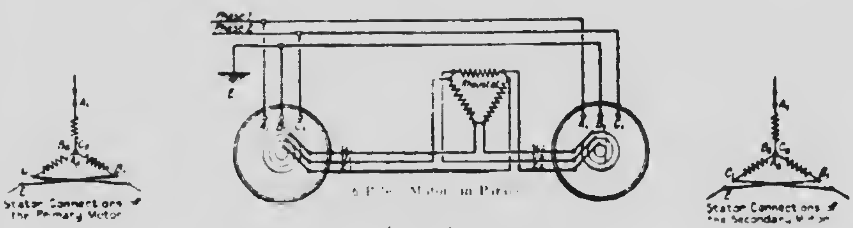


Fig. 1,787.

Diagrams of Connections of Two Three-phase Induction Motors for Four Synchronous Speeds.

The method of "cascade" adopted is to place the rotors of the two motors in series, starting resistances being in the stator circuits of the secondary motor. The change over from 8 poles to 6 is made by altering the interconnections of the windings with special change-over switches, which, for the rotors, are part of the rotor itself and revolve w[illegible] [illegible] mechanism for one of these switches is shown at s, Fig. 1782.

IV. ELECTRIC LOCOMOTIVES

The two preceding sections have dealt, directly and by reference, with the details of the c.c. and the A.C. motors used in electric railway traction, and the details of the collecting gear, whether for overhead or insulated rail conductors, have been dealt with in the last chapter. At page 1500 we have also briefly referred to the questions underlying the use of motors

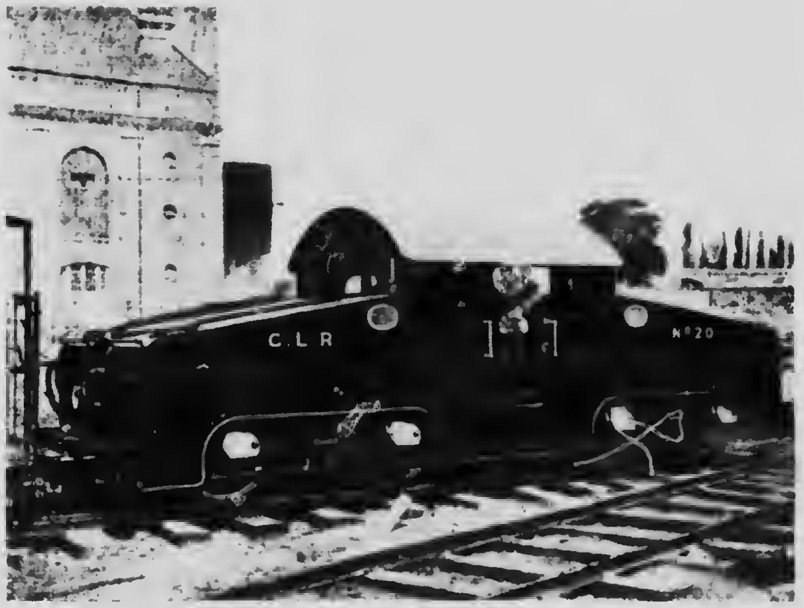


Fig. [illegible].—Early L[illegible] [illegible] C[illegible] [illegible] Ra[illegible]

distributed along the train as compared with the assembling of [illegible] whole driving power on a single vehicle or locomotive, which is the only [illegible]thod practically available in steam railway working. We now propose to give a few details of some typical electric locomotives, but shall [illegible] [illegible]ost questions relating to the control of the assembled electric pla[illegible] [illegible] [illegible]e dealt with in the next chapter.

Many mechanical problems have to be solved when designing an electr[illegible] locomotive, which lie outside the scope of this book and [illegible] which, there[illegible]fore, we cannot refer in detail. In fact, most of the problems except those which we are treating separately elsewhere are of this nature. The electric locomotive, however, is in itself so interesting, [illegible] [illegible] regarded as one mor

London Railway, opened in 1890.

Gearless Locomotives. By 1900 when ... the design both of traction motor ... had undergone considerable development. ... that ... this railway ... axles ... Fig. 1771 ... 1788, of which dimensions ... 1789 ... The locomotive ... driven ... motors described on page 160 ... mounted ... to that shown in Fig. 1771 ... elsewhere ... pages 165 to 195 ... The ... length was ... feet 8 inches ... weight ... The ... the rail level was ... was 67,000 lb. ... of 34,000 lb. ...

As compared with ... railways ... locomotives were ... excessively heavy, but they were eventually ... and their ... taken by distributed motors, in great measure ... by the freeholders along the ... set up by the locomotive ... notwithstanding the fact that the ... was sunk a considerable distance below ... part of its length, situated under the ...

... just described, with its armature ... locomotive, is mechanically the simplest ... power transformed by the motor to the ... already (page 1602) indicated some ... gearing or some other form of driving ... interposed between the armature shaft and the axle ... wheels.

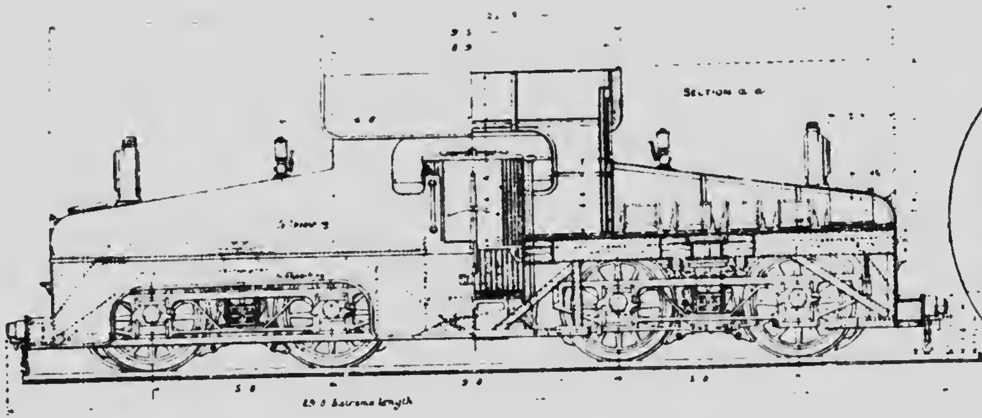


Fig. 1,758.

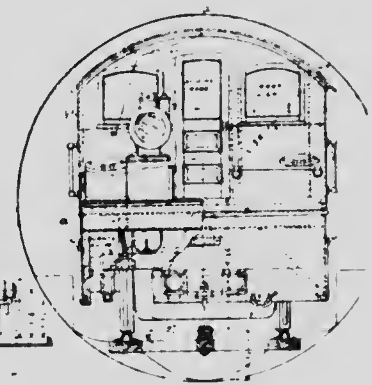


Fig. 1,760.

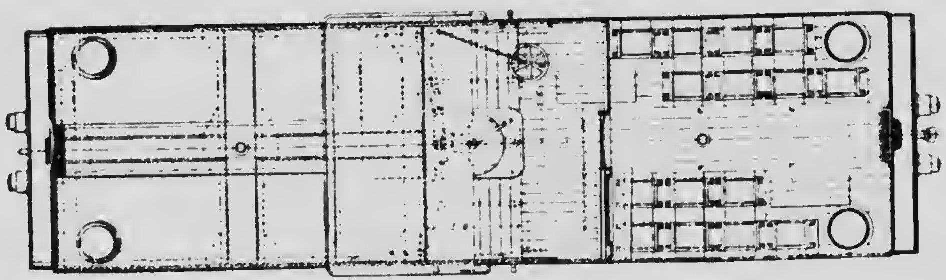


Fig. 1,761.

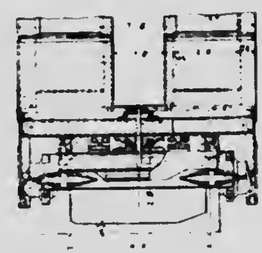


Fig. 1,759.

Details and Dimensions of the First Form of Locomotive used on the Central London Railway ([illegible])

The gearing used is some form of wheel and pinion spur gearing, which is now usually a *single-reduction gearing*. In the early days double and even treble-reduction gearing was designed and used, but improvement in the design of motors, and consequent lowering of the running speed of armatures, has removed the necessity for the more complicated forms.

The only other form of mechanism in ordinary practical use is the "*side rod drive*," usually with coupled driving wheels. The details of some examples of this method will be given presently. It has the advantage of distributing the driving power of one or two motors over several pairs of driving wheels, thus enabling higher-powered motors to be used and so diminishing the actual cost per effective horse power.

In this connection, it is practically a matter of indifference whether the motors be C.C. or A.C. motors, though the different control, transforming and safety equipment required by the different types of motors may considerably affect the design and external appearance of the locomotive.

Locomotives with Single reduction Gear. Dealing first with locomotives driven by motors with single reduction gear, we have already (see page 1000), in describing a modern C.C. traction motor so geared, called attention to the desirability of interposing an elastic connection between the two shafts. In suspending them from the framework of the truck, elastic buffers, as they may be called, should also for similar reasons be interposed, and these again usually take the form of strong spiral springs. Details of these suspensions will be found in special treatises.

What is of more relevant interest to us here is the electrical equipment of a locomotive and its arrangement in a typical modern example. We select for illustration the freight locomotive brought into service in 1910 by the North Eastern Railway Company on the Shildon Newport section of its system. An external view of this locomotive has already been given (Fig. 1,720), in describing its picking up gear, which consists of two large pantographs. The general "lay out" of the electrical machinery and apparatus is indicated in Fig. 1,76[illegible], which is a side elevation to scale, and partly in section of the same locomotive.

The locomotive is an articulated double-truck vehicle having a total length over all of 39 feet 4 inches and weighing 74 tons, to which the electrical equipment contributes 24·25 tons, though the actual weight of the four motors is only 9·15 tons. The buffers and the drawbar and spring between the two trucks are clearly shown, together with other mechanical details. The efficiency curves of these motors with and without gears have been given on page 1002.

The two motors at the right-hand end are shown partly in section, and it may be noted that the centre lines of the armature axles are slightly higher than the centre lines of the driving wheels (cf. Fig. 1,77[illegible]). Th the centre part of the cab there are two motor dynamos or dynamotors driving ventilating fans, which drive air through the motors, sliding glands being provided to take up the displacements continually occurring whilst the locomotive is running. One of these dynamotors also drives an air compressor for the brake and other services, the air reservoirs being placed one at each end of the locomotive. The generator part of each of these machines also provides a low-voltage current for lighting and other purposes, for, as already explained elsewhere, the current supplied is at 1,500 volts. The contactors and resistances for each pair of motors are carried in the sloping compartments at the corresponding ends of the locomotive, and there is a controller at each end of the central or working compartment, so that the engine can be worked in either direction. The pantographs have been described elsewhere (*see* page 1566); in Fig. 1,703 one of them is shown raised and

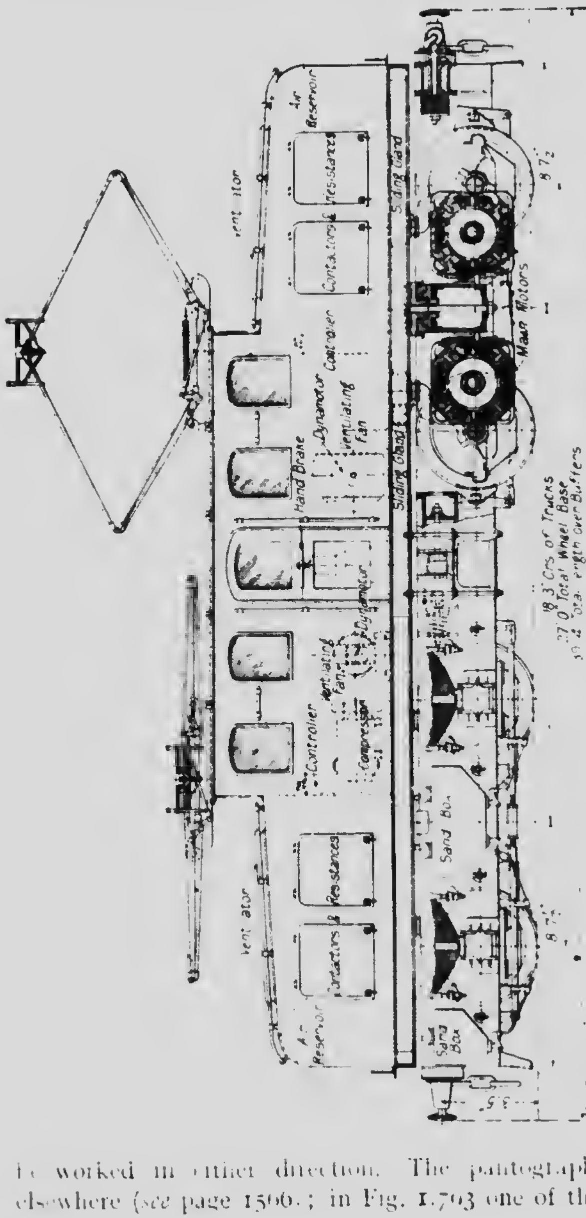


Fig. 1,7.. General "Lay-out" of ... Locomotive with Single-reduction Gear.

the other collapsed. They are raised by compressed air, and, as mentioned on page 1567, access to the low roofs from which they can be reached can only be obtained through a door, by opening which the air pressure is released and the pantograph lowered from contact with the high-voltage live conductor.

Locomotives with Side-rod Drives. The above will give our readers some idea of the electric C.C. high-voltage locomotives employed for ordinary railway service, especially of the suburban and interurban type, in which the separate axles are driven by single-reduction motors without any side rods or coupling of driving wheels. We now proceed to deal with side-rod driven locomotives, in which the motors may be

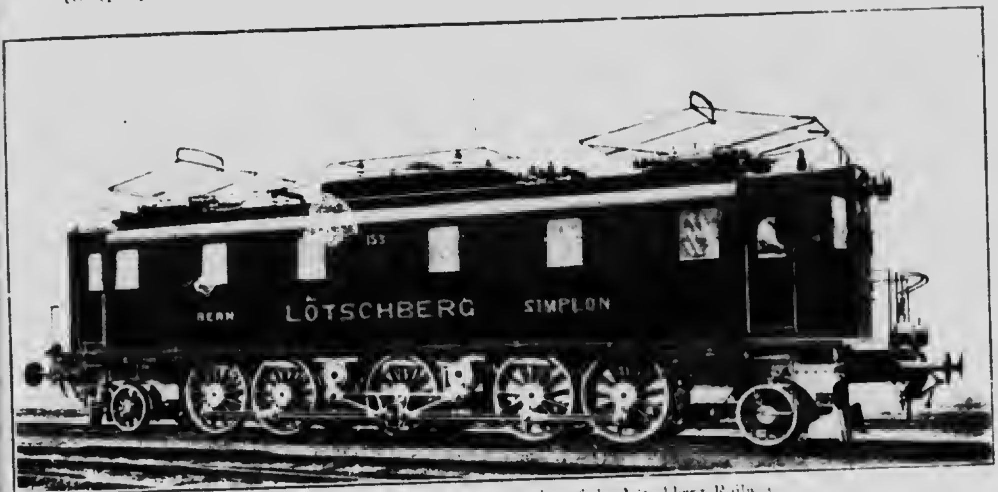


Fig. 1,794.—The Oerlikon A.C. Locomotive of the Lötschberg Railway.

either C.C. or A.C., and we select first the locom[otive] used on the Lötschberg Railway in Switzerland to which allusions h[ave bee]n made more than once in the foregoing chapters (*see* pages 807 an[d] [1]594).

The Oerlikon Lötschberg Locomotive.—The remarkable compensated series commutator motors described at page 807 *et seq.* built by the Oerlikon Works for the Lotschberg (Berne) railway, were carried on no less remarkable locomotive[s], which are worthy of attention. An outside view of one of these locomotives is given in Fig. 1,794, from which it can be seen that it is constructed to be driven from either end, and that there are five coupled driving wheels and two smaller running wheels on each side. The over-all length is 16 metres (50 feet), and the total weight 107 metric tons. The track is laid to the standard English gauge of 4 ft. 8½ in., and the maximum gradient is 2.72 per cent. or 1 in 37, which is a heavy one for adhesive running.

Each locomotive carries two of the motors shown in Fig. 831 (page 508), and it is of more than passing interest to note how these sixteen-pole motors are mounted on the locomotive. The mounting is illustrated in Fig. 1,795, which shows the middle part of the locomotive with the side removed. The motors are placed side by side, and drive by the gearing, particulars of which have been already given (*loc. cit.*), and the pinions illustrated in Fig. 833. These pinions drive the two outside axles A A, which, by means of the triangular braced coupling, drives the axle B of the centre driving-wheels, to which the other four driving wheels are coupled as shown. The mounting of the various axles has been carefully worked out so as to give the necessary play in going

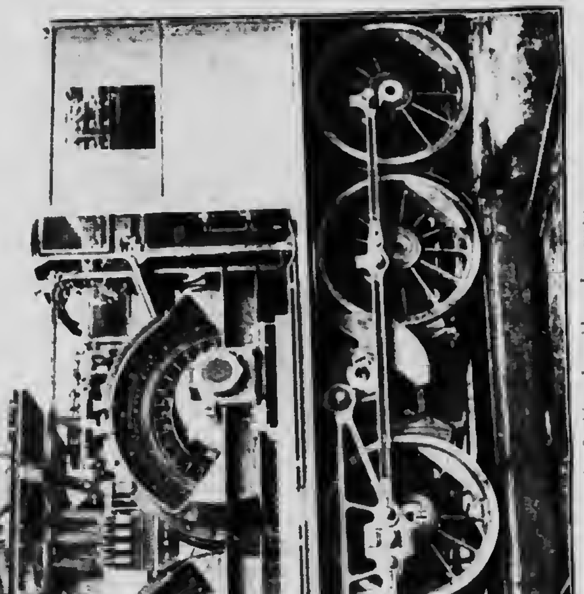


Fig. 1,795.—The Gearing and the Position of the Motors on the Oerlikon Lötschberg Locomotive.

round curves. The locomotive is capable of developing 2,500 h.p. at a speed of 50 km (31 miles) per hour on a 1.5 hour's rating, and can haul a train of 310 tons up a gradient of 2.7 per cent; the maximum speed is 75 km (46.6 miles) per hour. At starting the draw bar pull can be increased by 30 per cent.

The A.C. single-phase power is collected at 15,000 volts and 15 periods per second from an overhead trolley wire with a catenary suspension by bow collectors of the pantograph type. From these bow collectors (described on pages 1563-64), which are worked by compressed air, the current is led through high-voltage oil switches and fuses to the primaries of two air-cooled transformers, each of whose secondaries is connected by no fewer than twelve tappings to a drum controller, which is mounted on the top of the transformer so that the heavy secondary currents, which may be as much as 2,000 amperes per motor, go by a short path to the controller. This controller and details of the methods of control employed will be found described in the next chapter (see page 1605).

The equipment of each transformer and controlling set is complete in itself, so that the train can be run with one motor and switchgear, or the two equipments can be worked either in parallel or in series. Further, both motors can be fed from one transformer with the motors in series, whilst full speed can be maintained with one motor alone.

The high-voltage circuits in the machine-room are in two compartments closed by lattice-work doors, so locked that the high-voltage circuit in front of and behind the high-voltage oil switch has to be earthed before the door of the compartment containing the switch can be opened. Also, the key cannot be withdrawn from the lock until all the doors are closed, and when withdrawn it has to be used for turning on the pressure air to raise the bow collectors; further, when the air tap is turned on the key cannot be removed until the tap is turned to a position which discharges the pressure air and allows the collectors to drop, thus cutting off the 15,000 volts from the locomotive. It would thus appear to be impossible for any attendant, either carelessly or wilfully, to come into contact with a live high-voltage circuit. Even if he attempts to climb on to the roof of the car by the only ladders provided a warning signal is given if a ladder be placed in the necessary position whilst the car circuits are "alive." There are other interesting mechanical features about this locomotive, a full description of which would lead us beyond the scope of this book.

Swiss Mountain C-C Locomotives.—The system of side-rod drive, with connecting rods driving the coupled wheels from intermediate shafting, is a favourite one on the Swiss mountain railways, where the conditions are severe and the gradients heavy, but for lower-powered engines the details of the drive are not always so complicated as in the example just described. A fairly simple arrangement is shown in Fig. 1,796, which depicts the motor mounting of a narrow-gauge locomotive on the Bernina Railway in Switzerland. The supply is overhead by continuous currents at 750 volts. The intermediate shafts are driven by the usual single reduction gearing, but with the cushioned rims described at page 1609 above, and the connecting rods both drive on to the central wheel of the triple driving wheels. Each motor can develop 155 H.P., and there are two trucks to each locomotive. The total power is therefore 620 H.P., with which the locomotive is designed to start a 110-ton train and maintain a speed of 11.2 miles per hour on the most severe gradients on the line. The locomotive which successfully accomplishes these requirements is shown in perspective in Fig. 1,797 attached to its 110-ton train. The general structural details and some of the principal dimensions are given in Figs. 1,798 and 1,799, which are outline drawings of a side and an end elevation respectively of the locomotive. It is 15 feet 7 inches long but only 8 feet 2 inches wide, as, for engineering reasons, the track is laid for the narrow gauge of one metre (39.37

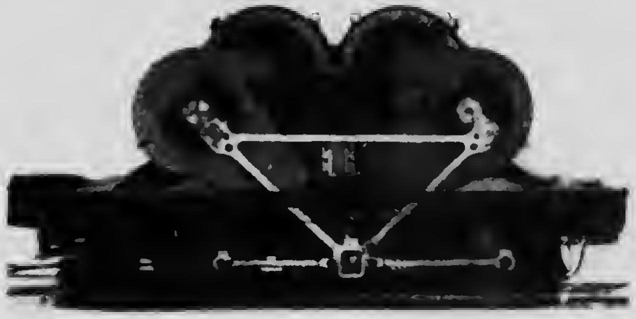


Fig. 1,796.—Motor Mounting on a Swiss Railway.

Fig. 1,797.—Narrow-gauge Locomotive for Swiss Mountain Railway.

inches. The whole locomotive weighs 46·86 tons, of which 18·7 tons is due to the electrical equipment, but can carry 3·3 tons of goods, so that the maximum weight available to give adhesion for traction is 50·16 tons. This locomotive can develop 17 H.P. per ton of weight on its one-hour rating.

Italian Three-phase Locomotives.—Two types of locomotives as used on the Italian State Railways are shown in Fig. 1,800. The supply cur-

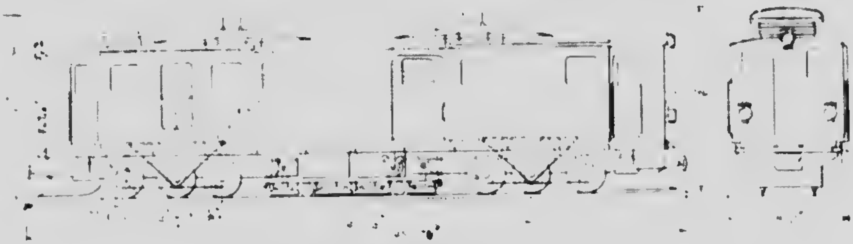


Fig. 1,798. Fig. 1,799.
Outline Drawings of Mountain Railway Locomotive.

rents are three phase 3,700 volts at 16·7 periods per second, and the double collecting bows for the two overhead trolley wires can be out in the figure. The line on which these locomotives work Savona to Ceva in Piedmont, and has long and severe gradient locomotive on the left is designed to attain a speed of 31 miles per hour on the steepest ascent, on which the most powerful steam locomotives could not exceed a speed of 15 miles per hour. It has coupled driving wheels with a side rod drive, and at full speed develops 2,200 H.P. The locomotive on the right with only six, but

Fig. 1,800.—Italian Three-phase Locomotives.

larger, driving wheels is capable of attaining a speed of 62 miles per hour, developing 2,600 H.P. at that speed.

The three-phase induction motors described on pages 1610 *et seq.* were installed by Messrs. Brown, Boveri & Co., in locomotives for the Italian State Railways. A sketch elevation of one of these locomotives is given in Fig. 1,801. They are designed for fast service only over a line of heavy gradients and sharp curves, upon which they attain a speed of 62 miles per hour. The sketch shows the general arrangement of the two motors, the driving gear and linkages, and the positions of the chief electrical apparatus. At each end of the frame of the locomotive, which is carried by three pairs of coupled 64-inch driving wheels, there is mounted a jack shaft, one for each motor, and outside each of these jack shafts there is a swivelling four-wheeled truck. The motors are placed at a high level, thus raising the centre of gravity of the whole locomotive and necessitating the driving of the jack shafts by fairly long connecting rods which are inclined at an angle of about 33°. The centre lines of the jack shafts are at the same level as those of the driving wheels, the coupling rods of which are driven by horizontal main rods extending between the jack shafts and the nearest pair of drivers at each end.

It will be remembered that the motors have four synchronous speeds (*see* page 1012), in changing from one to another of which there are some-

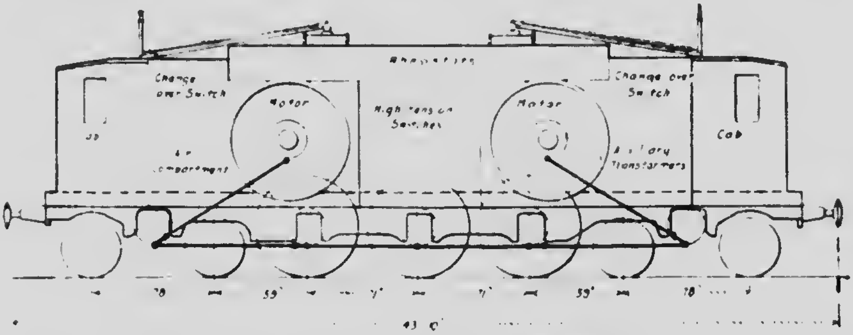


Fig. 1,801.—Sketch Elevation of an Italian Three-phase Locomotive.

what complicated switching arrangements. The change-over switches are carried in the positions indicated at each end of the cab. Air compressors and apparatus for operating certain parts of the equipment are placed at the left-hand end of the cab, and transformers for auxiliary circuits are carried at the corresponding position at the right-hand end. The whole of the high-voltage apparatus is carried in a separate compartment in the middle of the locomotive, and the usual safety precautions alluded to above are observed. Finally, the starting rheostats, which are metallic and very numerous, are placed in a compartment over 20 feet long on the top of the cab. Brakes can be applied pneumatically to all the wheels, and the driving wheels can be braked by hand.

The over all dimensions of the locomotive are 43 feet 10 inches long by 9 feet 8 inches wide, and it has a gross weight of 102 tons. The maximum value of the tractive effort is 27,000 lb.; at the two lowest speeds the ordinary value is 20,000 lb., increasing up to about 21,000 lb. at the third speed, and diminishing to 13,500 lb. at the highest speed. These two latter figures give the effective power at the third and at the highest speeds as 2,500 H.P. and 2,230 H.P. respectively.

Single-phase Supply and Three-phase Motors. In the foregoing examples the power used in the motors is similar in character to that taken from the supply conductors, but we now give an example in which three-phase motors are driven from a single-phase supply. The example chosen is the single-phase locomotives installed on the Pennsylvania Railway in 1917,

Fig. 1,802.—High-voltage Single-phase Locomotive (Pennsylvania Railway).

and supplied with current at 11,000 volts 25 periods per second. A perspective view of the locomotive, which has novel mechanical as well as electrical features, and is 76 feet 6 inches long and 10 feet 1 inch wide over all, is given in Fig. 1,802, and it may be noted that the collecting pantograph, which is shown raised, has been more fully illustrated and described in Fig. 1,718, on page 1564. The locomotive is mounted on two trucks, each of which is driven by three pairs of 6-foot driving wheels on a rigid wheel base 13 feet 4 inches long, but with a jack shaft and a pony truck outside this wheel

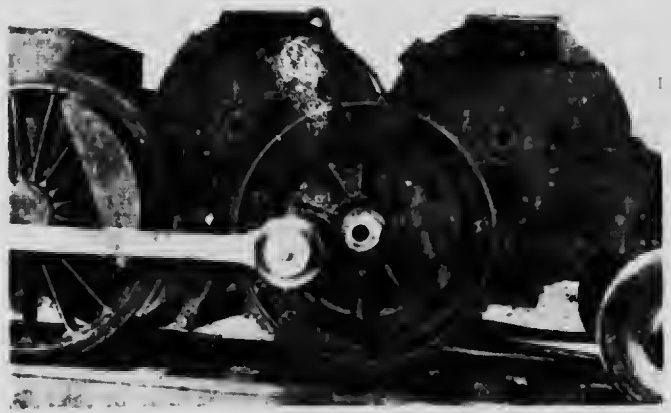


Fig. 1,803.—Mounting of the Three-phase Motors.

base. The rigid wheel bases are flexibly articulated with bumper girders interposed in contact with each other and surrounded by a massive link, which extends down and forms a rigid part of the cab structure.

Each truck is driven by two three-phase induction motors mounted as shown in Fig. 1,803, and driving a single jack shaft through pinions at each end of each armature, meshing into flexibly mounted gear rims carrying helical teeth. A similar cushion gear drive has already been described on page 1609. The jack shaft drives the side rods as shown in Fig. 1,803, the details being more fully given in Fig. 1,804, which shows one end of the cab, including one of the rigid trucks and the central section; the side of the cab is removed and some of the machinery is shown in section. The 11,000-volt single-phase current is transformed into 850-volt three-phase current for the motors by means of step-down transformers and phase converters. The general theory of such a conversion has been

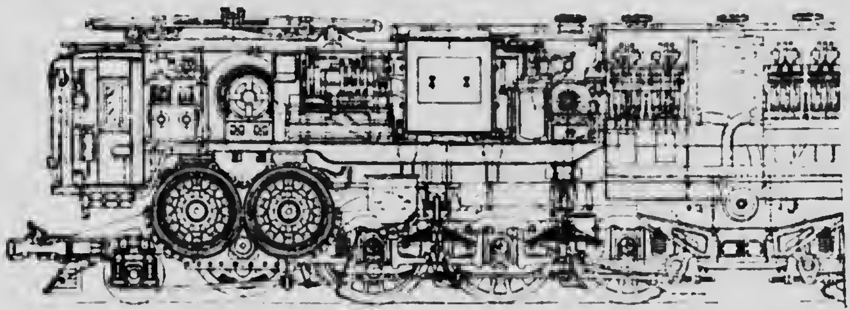


Fig. 1,804.—Side View (partly in Section) of One-half of the Locomotive.

referred to on page 949; this particular application will be more fully described in the next chapter (*see* pages 1695 *et seq.*)

Each of the motors is rated at 1,200 H.P., and therefore the rating of the locomotive is 4,800 H.P., but it can develop as much as 7,000 H.P. at starting. As the motors are induction motors, and for ordinary running are connected in parallel, there is only provided one normal operating speed, which is 20·6 miles per hour—a speed which is considered to be the maximum safe speed for the heavy trains for which these powerful locomotives were designed. For protracted slow movements, however, the motors can be connected in "cascade" (*see* page 1699), reducing the speed to about one-half, but with a low power factor. The tractive effort developed at maximum speed is 87,200 lb., and the method of obtaining intermediate speeds is explained later (*see* page 1699).

Battery-driven Locomotives.—It is obvious that for certain classes of railway and general work a self-contained locomotive, carrying its own supply of energy, is not only useful but practically necessary for economical working. Everyone is familiar with the fussy little steam locomotive used for shunting and running loads about large works. It is further obvious that overhead conductors or third rails at ground level are not at all convenient for the supply of electric energy for such purposes, and the storage battery as a source of the necessary energy naturally suggests itself. The outcome of these obvious facts is that battery locomotives serve a distinct and useful purpose, and, in contrast with the above high powered locomotives, we describe such an engine, selecting our example almost at random from quite a number which are available.

An electric shunting locomotive of this type used by the Midland Railway

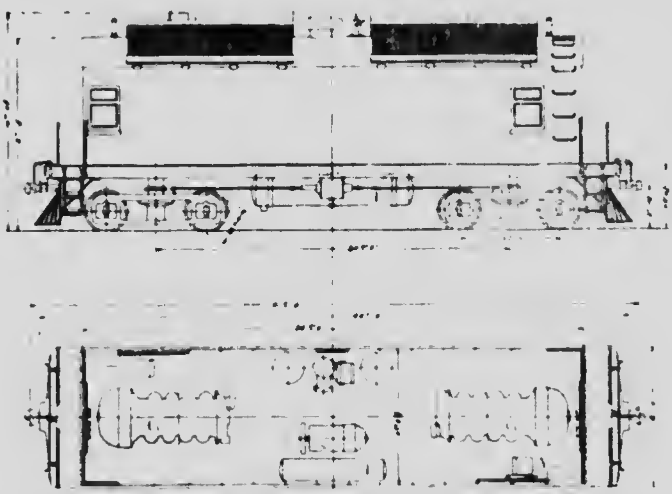
Fig. 1,805.—A Battery-driven Shunting Locomotive.

at the West India Dock, London, is shown in Fig. 1,805. A 108 cell "D P" battery, with a capacity of 108 ampere-hours, is carried in the two end compartments, whilst the central cab contains the usual series-parallel controlling equipment, and the necessary switches for charging the cells. The battery is charged for one or two hours every day from 12.30 p.m., and is given a "refreshing" charge before starting work in the morning, the charging current being taken from a motor generator set, as the supply voltage of 400 volts is too high for the use of a negative booster. The driving power is transmitted to the axles by two Dick Kerr motors, one for each axle and each of 22 H.P., the working current varying from 40 to 90 amperes with an occasional current running up to 150 amperes. The controller is arranged for electric braking, and in addition a band brake, operated by hand, is fitted on each axle. The battery boxes are well ventilated.

Petrol-electric Locomotives.—The battery locomotive does not,

Fig. 1806.—An American Petrol-electric [illegible]-ton Locomotive.

however, exhaust the possibilities of self-contained locomotives which may fairly be described as "electric." As in road traction, so for railways, it is possible to have the combination of a petrol-driven generator supplying current to a motor or motors which drive the locomotive. In fact, this is only reverting to an earlier type of electric locomotive, which at one time attracted a good deal of attention. We refer to the Heilbron locomotive of which mention has been made in an early edition of this book, and in which a steam-engine was used to drive the generator.



Figs. 1807 and 1808.—Elevation and Plan of a Petrol-electric Locomotive.

The case of petrol-electric road vehicles has been dealt with at length in a previous chapter (*see* pages 1499 *et seq.*), and it will be remembered that for these the electric equipment chiefly appeared as a substitute for the mechani-

[illegible]ally bad gear box of an ordinary petrol driven vehicle. This chapter may fitly conclude with a brief reference to the corresponding case in railway working, in which the electric equipment plays a much more important part, inasmuch as it may be used to subdivide the power of a large petrol engine between two or more motors, much as in the case of the "Thomas" transmission for road vehicles referred to on page 1507. In the railway case, however, the possibilities are greater, and have been developed further.

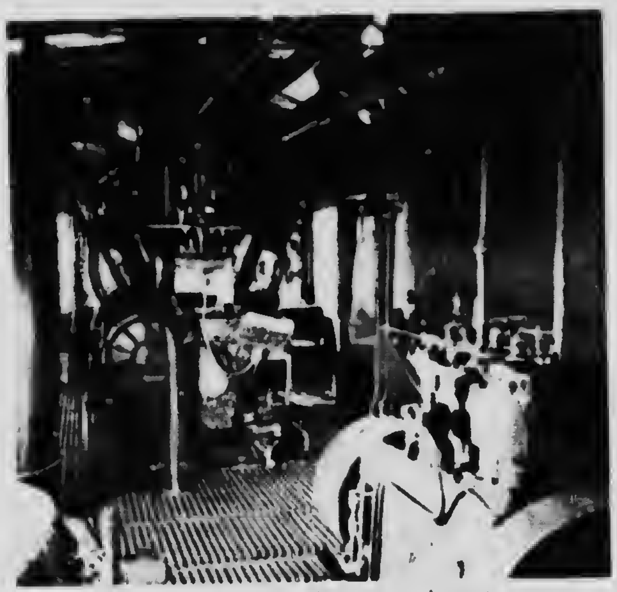


Fig. 1,80[illegible].—Interior of a Petrol-electric Locomotive.

An external view of a 60-ton petrol-electric locomotive, capable of developing 350 H.P., is given in Fig. 1,806. It was built for the Minneapolis St. Paul, Rochester and Dubuque Electric Traction Company for a section of their system 107 miles long, running from Minneapolis to Mankato. This section is operated entirely by locomotives of this type. A line elevation of the locomotive is given in Fig. 1,807, and a line plan in Fig. 1,808. These line drawings show the general arrangement of the apparatus and have the principal dimensions marked upon them. The length of the cab is 34 feet

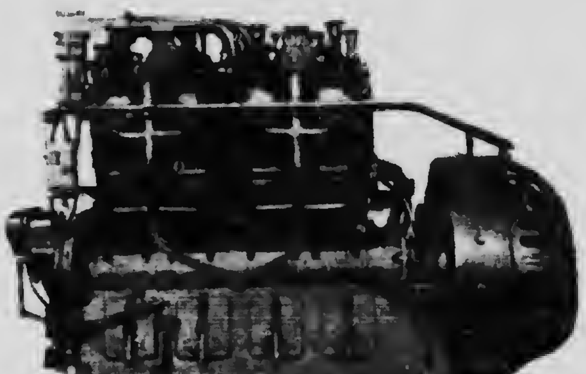


Fig. 1,80[illegible].—A Petrol-electric Generating Set.

and the over-all length 41 feet 4 inches, whilst the width is 9 feet 0 inches and the height nearly 15 feet.

The fuel is carried in a 300-gallon petrol tank 1 (Fig. 1,808) installed beneath the underframe, and there are two generating sets G G, which occupy the two ends of the cabs, a view of the interior of which is given in Fig. 1,809, which shows one of the generating sets in the foreground. An air compressor A is driven off the crank shaft of each engine, and supplies the compressed air for the air-brake system and for starting the engine. The air reservoirs, three in number, are installed on one side of the cab. One of the generating sets is shown in Fig. 1,810. The engine is an eight-cylinder petrol engine of the V type, running at 550 R.P.M., and capable of developing 175 H.P.; it is directly coupled to a 600-volt compound-wound generator having commutating poles. There is also a small 5-kilowatt petrol-electric generating set *g* (Fig. 1,808), which, running at 750 R.P.M., supplies current at 65 volts for lighting the cab, the train carriages, the head lights and for other minor purposes. There are four motors, two on each truck, each motor being capable of developing 100 H.P. for one hour. They are 600-volt, series-wound, commutating pole, box-frame machines, similar to those described at pages 1605 *et seq.*, and the two motors on each truck are permanently connected in parallel, the two pairs being controlled as if they were single motors. The control of the speed is based upon the variation of the field strength of the generator, and not upon wasteful resistances in the main circuit. It is therefore more economical than the ordinary rheostatic series-parallel control described in the next chapter. By varying the field of the generator the voltage of the current can be varied to give the speed required, and as there are 15 efficient running positions of the controller, there is a large choice as well as a wide range of speeds. The two top speeds are obtained by shunting part of the series fields of the motors

Fig. 1,811.—Westinghouse Petrol-electric Railway Coach

There is a controller at each end of the cab, so that the locomotive can be run in either direction. The tractive effort is 16,000 lb. at 5 miles per hour, and 3,500 lb. at 30 miles per hour.

Petrol-electric Railway Coaches. It is obvious that the above method of operating can be adapted for lighter traffic. A railway motor coach so driven is shown in Fig. 1,811. It has a seating capacity for fifty passengers, and is one of a set supplied to the Great Central Railway Company by the British Westinghouse Company. There are two motors which can develop a maximum of 90 H.P., and there is a controller at each end, so that the coach can be run in either direction. Where the traffic is light, such coaches have the advantage of enabling the operating company to test whether the traffic offering is sufficient to justify complete electrification with its heavy initial outlay.

In conclusion the reader may be reminded that an outstanding advantage of the petrol-electric drive is the fact that the engine can always be kept running at its most economical high speed, whatever the speed of the vehicle may be.

CHAPTER XVII

CONTROL OF THE ELECTRIC POWER IN TRACTION WORKING

ONE of the greatest advantages of the use of electric energy for traction purposes is the ease with which it lends itself to manipulative control by the individual responsible for the running of the vehicle or vehicles. The general principles to be observed are simple, and the difficulties which arise in applying them in practice are neither insuperable nor even great. Like all other problems, however, in practical engineering, compromise has often to be resorted to, and the "survival of the fittest" is as prominent a feature in the development of the appliances in practical use in this connection as it is in other branches of engineering. Matters of great interest also arise from time to time which well illustrate the interdependence of electrical laws and phenomona.

It will be convenient to deal first with the methods of control ordinarily used in the working of single tramcars with continuous-current motors, as this leads up naturally to some of the methods employed in the more complex problems involved in the control of A.C. traction motors, and the still more complex problems of the control of railway trains.

I C.C. POWER CONTROL ON TRAMWAYS

The principles underlying the working and the control of the speed of continuous-current motors have already been considered at length in Chapter IV. (*see* pages 641 *et seq.*), and need not be restated here. We are now concerned only with their application to the efficient operation of electrically driven tramcars.

For reasons given elsewhere the properties and characteristics of the series-wound motor are much better adapted for the conditions of tramcar work with continuous currents than those of shunt or compound-wound motors, and therefore in the majority of cases series-wound motors are used. Such motors have a very low ohmic resistance between terminals, and when their armatures are not running would draw a dangerously high current if connected without any precautions to supply mains at full electric pressure. The subject has already been fully discussed (*see* page 642) in connection with the use of the motors for other purposes.

In the problem now being considered the use of a sufficiently large resistance in series with the motor to bring down the current at starting to safe limits would lead to heavy capital outlay, and would be very wasteful in practice when many stoppages have to be made at short intervals. Moreover it is mechanically good to have more than one motor on the car, both because this provides more than one driving axle which tends to more rapid acceleration, and also gives a reserve available if one motor should break down. It is therefore the almost universal custom to use not fewer than two motors, and in some cases more than two are employed. If two motors are available the starting losses and the low-speed losses can be diminished by putting the motors in series when it is necessary to start or to run at a low speed. In this connection attention may be called to the second curves upon Fig. 649, which give the effect of half-voltage on traction motor performance.

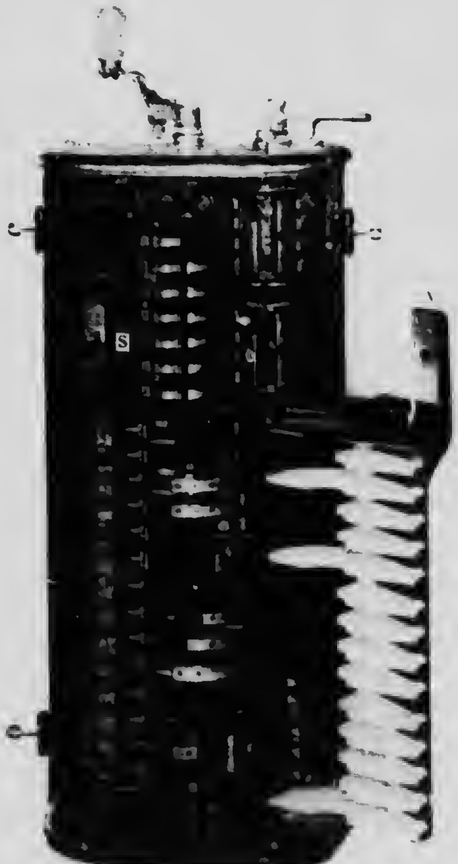


Fig. 1,812. B.T.H. Standard Tramcar Controller.

Series-parallel Control and Controllers.—Even with the motors in series, however, resistances must be introduced at starting, and removed step by step as the speed rises and increasing back E.M.F.s are developed in the motors. When all the resistances have been cut out, and each motor is receiving half voltage, the motors are switched into parallel so that each can obtain full voltage, but it is necessary to re-introduce resistances which are again cut out step by step as the speed rises further until the motors are running at full speed under full voltage. The method is known as the *series parallel* method of working, and the appliance with all its necessary accessories which are used for carrying it out is known as the "*series parallel controller*."

Such "controllers" in modern practice are always of the cylinder or drum type which has already been described in connection with the starting regulation and reversal of continuous-current motors (see page 645). Where two motors have to be controlled and arrangements made for the series of operations just described, the controller is necessarily more complicated

A good idea of its general internal appearance will be gathered from Fig. 1,812, which represents a standard pattern of controller manufactured by the British Thomson-Houston Company Limited. Many of the details of this controller are similar to the corresponding details of the controllers described elsewhere, to which reference should be made.

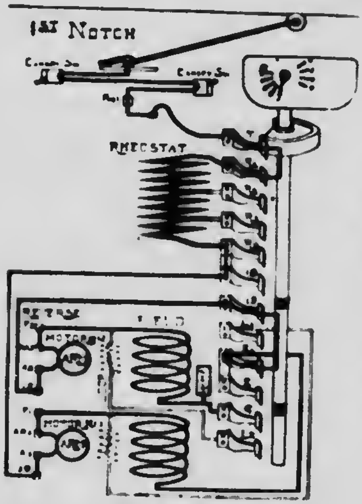


Fig. 1,813.—Diagram of Circuits with Controller on 1st or Starting Notch. Motors in Series.

Standard Operations. The general method of control is simple and follows the lines already set forth. On the first running notch of the controller the position is as shown diagrammatically in Fig. 1,813; the motors are in series with one another, and with all the resistances. The controller barrel is moved round the successive notches, as the speed increases the resistances are cut out step by step until they are all removed, and the two motors are in series with no added resistance. This is an economical running position, since all the power is being absorbed usefully in propelling the car, and it can run at the low speed economically, each motor taking about half the working voltage. In passing over the next two or three notches, none of which are running positions, changes in the connections are made such that on the next running notch the motors are in parallel with some resistances put back, as shown diagrammatically in Figs. 1,814 and 1,815. These resistances are then removed step by step on subsequent notches, and finally removed entirely, leaving both motors in parallel across the mains. That is the position, apart from other modifications, for the highest speed that can be obtained on the particular supply voltage available.

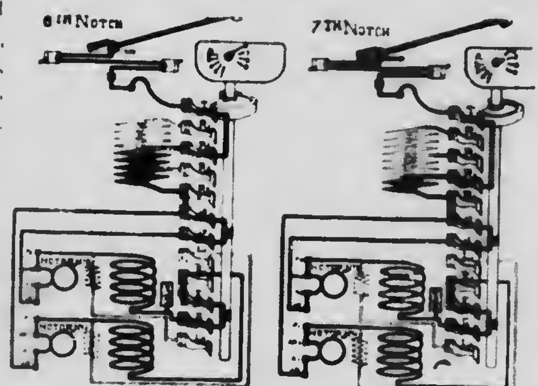


Fig. 1,814 Fig. 1,815

Sixth and Seventh Notches on Controller. Motors in Parallel.

The electrical connections for the various positions of the controller barrel so far described are shown diagrammatically in Fig. 1,816, in which the two thick vertical lines on the left and right represent the "+" and "—" mains respectively. The armatures and field coils of the two motors are indicated by A_1 A_2 and f_1 f_2, whilst the controlling resistances are shown by the zig-zag lines r_1 r_2 r_3. The coil s is the solenoid of the magnetic blow-out, to which reference will be made presently. Each of the horizontal series show the connections for one of the positions of the controller, these positions being numbered 1, 2, 3, 4 and 9 to 11. The resistances not in circuit are shown as short-circuited, and the reader will have no difficulty in making out the details with the aid of the foregoing description.

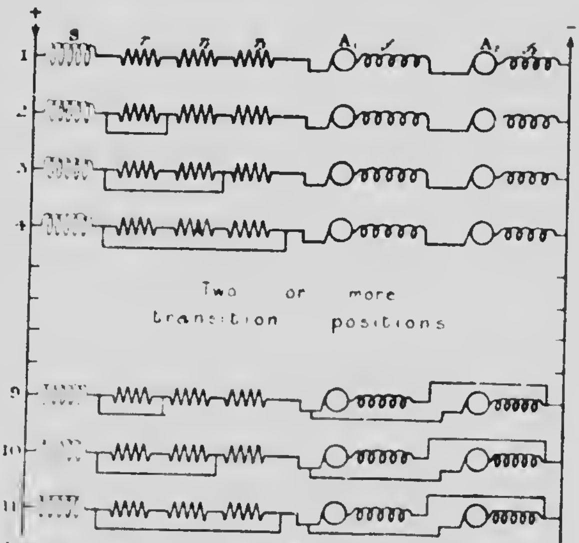


Fig. 1,816.—Diagram of Tramway Controller's Series-parallel Connections for Running Positions.

Between the positions "4" and "9" there are a number of "transition positions" for the changes necessary between the "full series" position of "4," which is an economical "running" position, and "9" which is the first of the "parallel" positions. It is in this "transition" zone that the chief electrical problem of the series-parallel controller presents itself. The nature of this problem will be understood from its solutions, three of which will now be given.

The simplest method is shown in Fig. 1,817, and may be called the "complete break" method. Two transition positions "5" and "6" only are required. In "5," which follows "4" of Fig. 1,816, the resistances r_1 r_2 r_3 are switched back into circuit, thus reducing the current very considerably before a complete break is made at X in position "6." This break is to be followed as quickly as possible by the barrel being turned to the next position "9" of Fig. 1,816 in which the circuit is restored by connections putting the two motors in parallel and simultaneously short-circuiting resistance r_1.

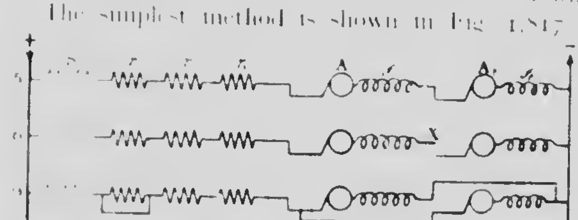


Fig. 1,817.—Controller Connections for Transition Positions. "Complete Break" Method.

The disadvantages of this method are obvious; there is first the sudden reduction of the current on moving from "4" to "5," and still more serious the breaking of the whole circuit "under load" on moving to "6." This deprives the car momentarily of its supply of power, and, since the load is inductive causes vicious and destructive sparking and arcing at the switch contacts.

To avoid these difficulties the "short-circuit" method, instead of breaking the circuit, short-circuits one of the motors before disconnecting it for the purpose of throwing it into parallel with the other. The "transition" positions of the controller for this method are shown in Fig. 1,818. In position "5" the connections are restored to those of "2" by the resistance removed in "3" and "4" being reintroduced. Passing quickly to "6" motor No. 2 is short-circuited and immediately afterwards in "7" it is taken out of circuit. This is only however for a moment, and in the next position "9" of Fig. 1,816 it is connected up again in circuit in parallel with motor No. 1 in the first of the parallel "running" positions.

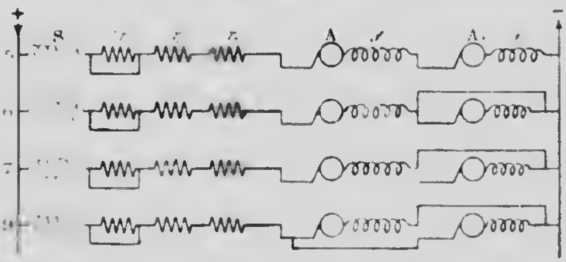


Fig. 1,818.—Controller Connections for Transition Positions. "Short-circuit" Method.

Although this method keeps the main circuit closed throughout the "transition" period the supply of power to the vehicle fluctuates, both because one motor is temporarily dead and also because the current through the other motor varies considerably. This may give rise to unpleasant jerks. Sparking is not entirely avoided because one contact through which a fairly large current may be flowing, is opened though the current in motor No. 2 must rapidly diminish when the motor is short-circuited.

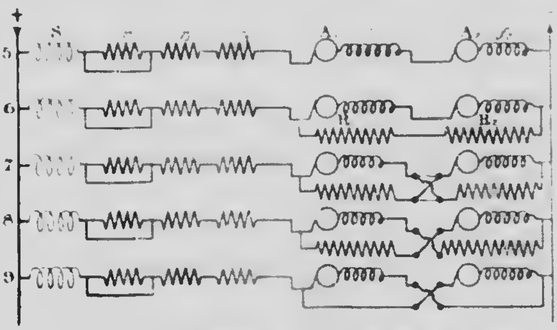


Fig. 1,819.—Controller Con[illegible] Transition Positions. "Bridge" Method.

Still another transition method is the "bridge" method, in which neither motor is removed from the circuit, even temporarily. The various successive positions are shown in Fig. 1,819 in which "5" [illegible] the same [illegible]

[illegible] in Fig. 1818 but in "6" instead of short-circuiting one motor both motors are "bridged" by two coils in series of such resistance that they carry a current about equal to that taken by the motors in position "5", the current in the motors is therefore not much disturbed. At [illegible] the equipotential points between the two motors and the two bridging resistances are cross-connected, as shown, and at "8" the "straight through" connections are broken so that the current from motor No. 1 passes through R_2 and that for motor No. 2 passes through R_1, the motors being now in parallel each with an added resistance in series with it. The barrel being turned to position "9" these added resistances are removed and the first "running" position in parallel is attained. The chief objection to this method is that in positions "6", "7" and "8" the current taken from the main is practically doubled.

The above details have reference only to the arrangement [illegible] for controlling the motors so far as connecting them in series or parallel and introducing the necessary resistances for different speeds and [illegible] concerned. In actual working other requirements cannot [illegible] and these will now be briefly referred to.

Reversing.—The general principles involved have already been fully explained in the chapter on continuous-current motors (see Section I, pp. [illegible]). With tramway series-wound motors the method adopted to reverse the direction of motion is to reverse the current in the armature, leaving the direction of the field flux unchanged. [illegible] and other reasons to be [illegible] the reversing [illegible] pieces are placed on a separate cylinder or barrel [illegible] on the right hand of the main [illegible] (Fig. 1821). [illegible] contact fingers [illegible] of the cylinder [illegible] reversing positions, namely [illegible] "forward" and [illegible].

[illegible] the two sets of fingers [illegible] Fig. 1822 [illegible] that the [illegible] of the armature [illegible] the left [illegible] connections. [illegible] forward [illegible] reverse [illegible] that the field [illegible] the [illegible] which [illegible] is running. [illegible] right [illegible] connect [illegible] the current from [illegible] the [illegible] that [illegible] exactly the same as those [illegible] in Section I.

[illegible] separate reversing barrel [illegible] the main barrel [illegible] that [illegible] main current [illegible] top cover of the controller is shown in Fig. 1,820 in which H is the handle which works the main barrel, and R that which works the reverser. The former is a fixed handle, but the latter is detachable, and can be carried away by the motor man if he has to leave his post at the controller. It can, however, only be detached when in the "off" position, so that the controller cannot be thus left if "alive." In its turn R can only be moved from the "off" position or *vice versa* when H is at the "off" position thus ensuring not only that reversals shall not be made whilst the main current is on but also that no currents shall be broken in the reverser barrel which therefore requires no "arc deflectors." The position of the main barrel is indicated by the pointer which is a prolongation backwards of the lower part of H, and in this position is not in danger of being covered up by the arm of the man operating H. The studs marked "power" etc., indicate clearly the positions to which this pointer is to be turned to bring the barrel to the various positions indicated in Fig. 1,816. As explained above, until R is turned to one of the running positions the handle H cannot be moved from the position "off." The interlocking mechanism can be seen at the top of Fig. 1,812, but its details are not very clearly shown.

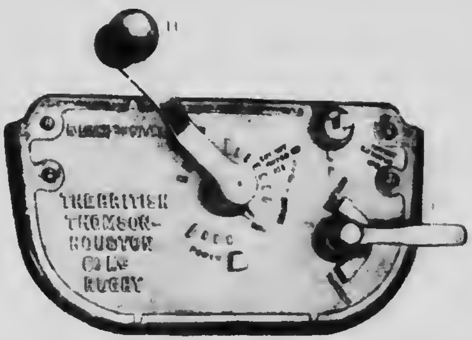


Fig. 1,820.—Top Cover of B.T.H. Controller.

Braking. Apart from the ordinary mechanical and other methods of braking, with the details of which we are not concerned here, the reversibility of the electric motor renders possible a method of braking which is peculiar to "electric" traction. Imagine a car travelling, say down hill, at full speed with its circuits quite disconnected from the supply circuits; the armature of the motors are necessarily being driven by the car, and if properly connected these motors can be made to act as generators. In this case the energy absorbed by the generators can only be drawn from the moving energy of the car, which is therefore retarded or "braked."

The simplest application of this principle would be made by arranging to provide, through the controller, the necessary connections for the motors so that their circuits could be completed through suitable resistances. This method has been tried in practice, but it is found that since the absorbed energy is eventually dissipated in the form of heat in the motors and in the circuit resistance, both of these, especially the former, get very hot. In fact, it amounts to this that the motors are being heated not only when driving the car, but also when the car is slowing down, and only have a period of cooling when the car is either standing still or "coasting."

Because of these difficulties the energy, whilst being partly absorbed by the electric generators, is now chiefly absorbed by magnetic track brakes energised by the currents from the motors acting as generators. The connections of the B.T.-H. controllers for this purpose are given in Fig. 1,822, where the coils of two such brakes are shown connected in parallel on one side to the earth fingers G, and on the other through a separate blow-out solenoid to the lowest finger B of the controller, which is in circuit only when the barrel is in one of the positions marked "brake." In none of these positions is the live finger T of the trolley wire in circuit. The motors, however, as shown diagrammatically in Fig. 1,821, are connected in parallel and in series with the controlling resistances R and the track brakes. The position of the main barrel determines how much of R shall be in circuit, this resistance being reduced as the tramcar slows down, and the E.M.F. of the machines diminishes; in this way the current on the brake solenoids is kept quite large until the car is running dead slow.

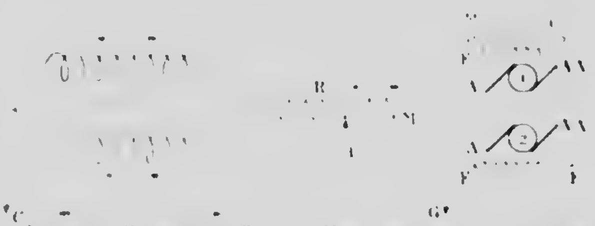
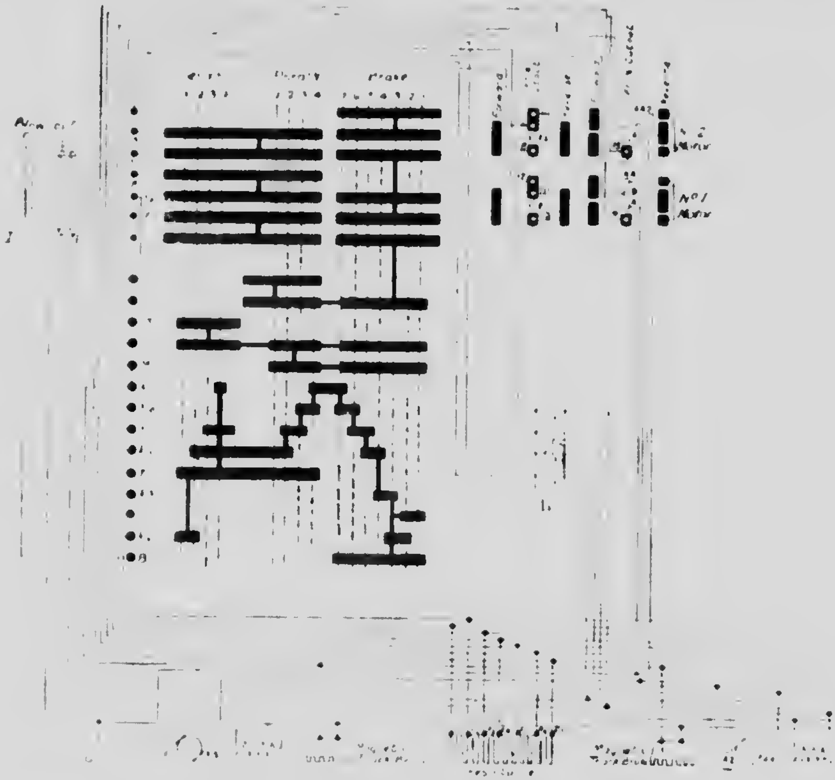


Fig. [illegible].—Connections of Tramway Motors as Generators for Braking.

The curious way in which the machines are paralleled in Fig. 1,821 should be noticed. Remembering that they are series-wound machines, it will be found that the field coils of No. 1 are in series with the armature of No. 2, and the field coils of No. 2 in series with the armature of No. 1. This is to prevent the disastrous consequences which would follow if by any chance the magnetism of one machine were reversed, in which case the machines would be in series with one another and on short-circuit. When, however, they are connected as shown, the direction of the current through one armature controls the magnetic flux of the other machine and ensures that they shall remain in parallel. Further, an examination of the "power" connections (Fig. 1,822) of the field coils will show that when braking the connection to earth is reversed. It will be a useful exercise for the reader to work out the reason of this for himself. Details of actual brakes are given later in Figs. 1,903 to 1,910.

Diagrams of Connections.—The actual connections in the case of a given controller are most readily followed by means of a "developed" diagram similar to those [illegible] (*see* pages 616 to 618, Section I) when dealing with controllers for stationary motors. Such a diagram for the B.T.-H. controller illustrated above (Fig. 1,812) is shown in Fig. 1,822.

The fixed fingers, 21 in number, which make contact with the various cylindric segments on the principal controller axle, are shown in a vertical line as black circles on the left-hand side of the diagram. The segments on the cylinder are indicated by longer or shorter horizontal bands which, on turning the controller handle, are brought into rubbing contact with the fingers opposite to them, the contacts for any given position of the controller handle being indicated by the vertical broken lines



Connections of B. T. H. Tramway Controller

numbered "Series 1, 2, 3, 4" and "Parallel 1, 2, 3, 4" this numbering being copied from the top outside plate of the controller.

The "reverser" cylinder contacts are shown at the top right-hand side of the diagram. On this cylinder there are two sets of fixed fingers 180° apart and these are indicated by the two vertical rows of white circles there being 8 fingers in each row. It will be remembered that there are only three possible positions for the reverser namely "forward" "off," and "reverse." In this case the cylinder segments are indicated by black vertical rectangles which, when placed over the fixed contacts as shown by the circles join these contacts electrically to the extent shown by the vertical black bands. In the diagram the "off" connectors are shown lying on the fixed contact studs the "forward" and "reverse" connectors being shown ready on the left and right-hand sides respectively.

The various pieces of apparatus to be connected electrically by the controller are shown diagrammatically at the bottom of the figure with the exception of the "blow-out coil" which is shown on the left-hand side. The apparatus consists of (i) the two motors indicated by their armatures A_1 A A_1 and A_2 A A_2 and their field coils F_1 F_1 and F_2 F_2 (ii) the controlling resistance in six sections with seven terminals, (iii) the two Magnetic Track Brakes and (iv) the connection to earth G, which is made through the frame and wheels of the car to the running rails. In addition there is shown on the right-hand side a special connection board B to which the field-coil terminals F_1 F_2 F_1 F_2 are connected. The actual connections between the apparatus and the fingers are shown by the vertical

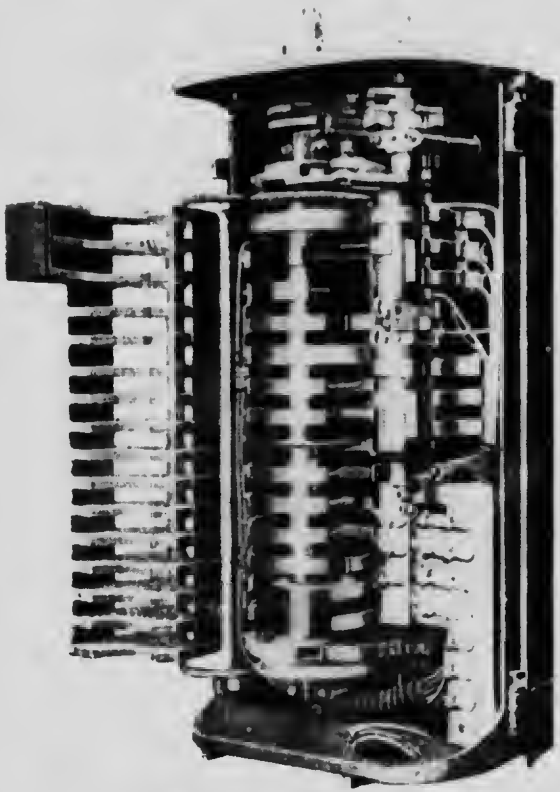
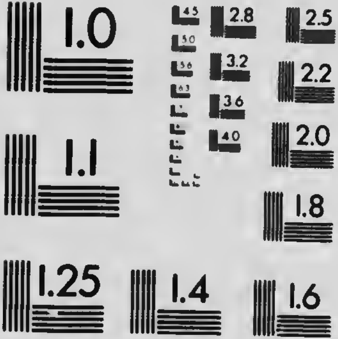


Fig. 52. Westinghouse [illegible]

and horizontal straight line lines, and can be readily traced by the corresponding numbers and letters which appear at the fingers and at the apparatus. Thus the reference F_2 will be found at one of the main barrel fingers, at the connection board, and at the field coil of motor No. 2. All these points are permanently connected. Similarly the connections between the fingers of one cylinder and those of the other are numbered at both ends with plain numbers 8, 9 up to 15 and the letter M. The trolley finger is marked T, and the earth fingers G. At the crossing points these

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



APPLIED IMAGE Inc

1653 East Main Street
Rochester, New York 14609 USA
(716) 482 - 0300 - Phone
(716) 288 - 5989 - Fax

diagrammatic connecting lines are not to be regarded as in contact except where contact is indicated by a black dot.

With these explanations to guide him the reader should now turn back to page 1635, and verify the connections for each of the running positions shown in Fig. 1,816, and also work out for himself the changes in the connections during the transition period between (Fig. 1,822) the Series "4" and Parallel "1" running positions.

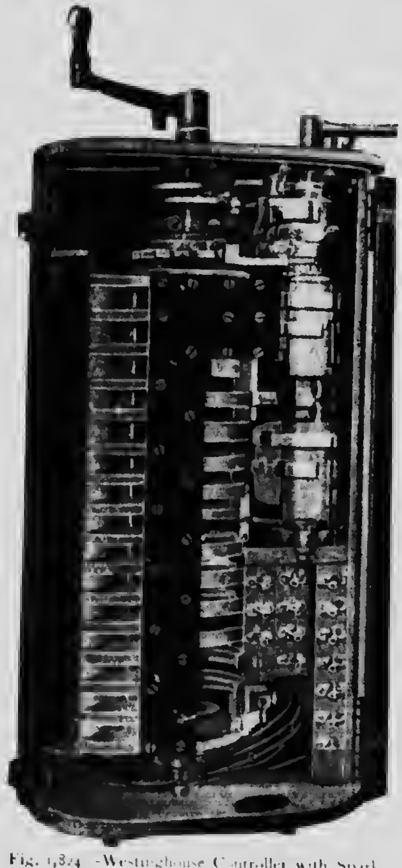


Fig. 1,824.—Westinghouse Controller with Spark Guard closed.

The "Brake" positions "1, 2 up to 7," not yet alluded to, are now easily dealt with. In the first place the controller cylinder, to pass from any of the running notches to a brake notch, must be moved through the position "Series 1" to the "off" position (not shown), and then onwards to "Brake 1," which is the first of the operative brake positions. Between "Series 1" and "Brake 1" there are some interesting successive changes. On first leaving "Series 1," contact is broken with all the 14 lower fingers, whilst it is still maintained with all but one of the upper fingers. This takes off the line voltage T, but leaves the motors connected in series as for ordinary running, but with one end earthed and of course "dead." On moving a little farther all connections are broken and the controller is quite "off." Before "Brake 1" is reached, however, there is a preliminary position, in which the ends of both field coils are earthed and the field of No. 2 motor joined to the armature of No. 1 motor preparatory to setting up on notch "Brake 1" the conditions of Fig. 1,821, that is, the motors connected in parallel with their fields crossed and farther in series with the two brakes (in parallel) and the controlling resistances R_1 to R_7, the blow-out coil being interposed between the resistances and the earth through which the circuit is completed to the field coils.

Anti-sparking Devices. Whatever the method of control adopted it is inevitable, in some of the changes from one position to another, more especially in the transition positions, that there should be sparking with a tendency for destructive arcs to form if there is any "hanging fire" during the change. Some method of minimising the resulting bad consequences is therefore desirable.

It will suffice to refer to two methods which have been widely employed. In the first of these fireproof and insulating partitions are interposed between the various fixed fingers of the controller so as to confine within a narrow space any arc which may be formed; in the second, in addition to this isolation, a magnetic field is used to blow out the arc, making use of the principle of the well-known "electric blowpipe" described in Vol. I. (*see* page 270).

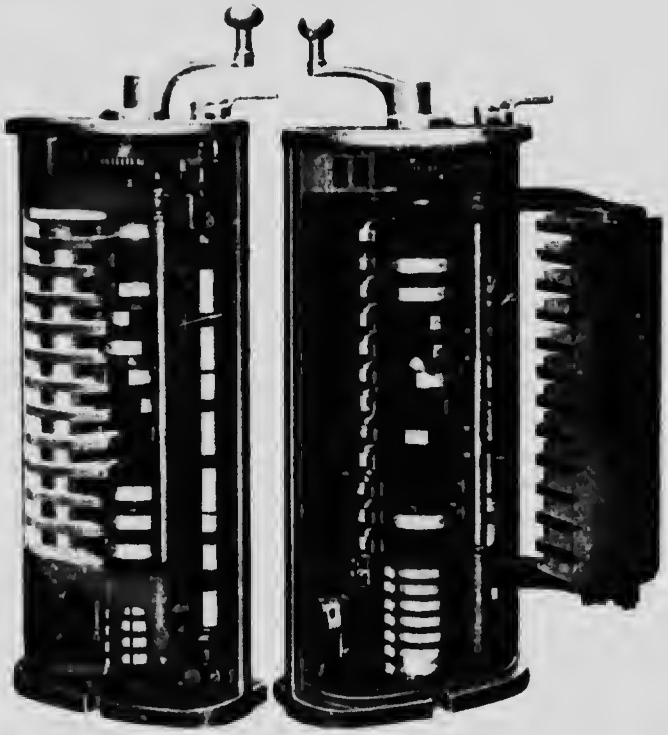


Fig. [illegible] Fig. [illegible]

Dick-Kerr Controller with Magnetic Blow-out.

The first of these methods is exemplified by the "spark guard," as it is called, of the Westinghouse controller which is shown thrown back or open on the left of Fig. 1,823, and in its working position or closed in Fig. 1,824. The substantial partitions shown are inserted between the consecutive fixed fingers (Fig. 1,823) with which the movable contacts on the main barrel engage, thus preventing any arcs forming from finger to finger or to the frame. The partitions are made of incombustible non-organic material.

Such incombustible partitions, though still widely used in other applications, e.g. switchboards, etc., to prevent "arcing over," have now been to a great extent superseded in tramcar controllers by the "electric" or "magnetic" blow-out referred to above, and the modern

Westinghouse controllers are so fitted. The B.T.-H. controller, already fully described, except as regards this device, is provided with a blow-out coil with a magnetic circuit so disposed as to produce a magnetic field across the space in which an electric arc may form when breaking circuit, and at right angles to the path of the arc current. The magnetising solenoid for the blow-out circuit is seen at s (Fig. 1,812). It has an oval section and a soft iron core, against the end of which the armature A fits when the shield with its deflector plates and partitions is closed in. The electric circuit of the coil is interposed between the trolley or collecting device and the finger T (Fig. 1,822), to which the line current is brought, so that whatever current is passed into the car it must flow through the blow-out coil. The magnetic blow-out field is only provided for contacts on the main operating barrel; no blow-out field is provided for the reverser barrel, for it will be remembered that the reverser barrel can only be operated when the main barrel is in the "off" position, and therefore the throwing over of these contacts cannot involve the breaking of a current or the forming of an arc.

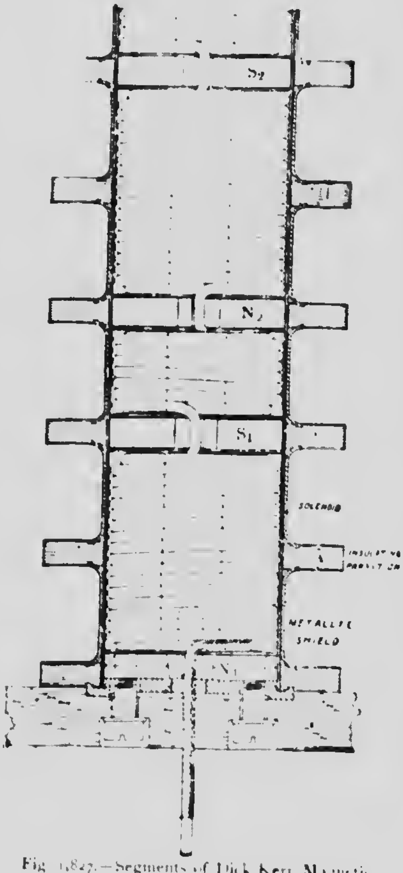


Fig. 1,827.—Segments of Dick Kerr Magnetic Blow-out.

Another method of applying the magnetic blow-out principle is used by Messrs. Dick, Kerr & Co. in their well-known traction controllers. One of these controllers is shown in Fig. 1,825 with the outer case removed, and in Fig. 1,826 with the blow-out device and its partitions swung back exposing the finger contacts. The device is known as the "metallic shield blow-out," and consists of a series of short solenoids carried on the swinging bracket, and so arranged as to produce the necessary magnetic gap across the break space at the finger contacts. This series of partitions is most clearly seen on the left-hand side of Fig. 1,825. A few of the lower segments of it are shown in section in Fig. 1,827. It will be noticed that the solenoid is not wound continuously in one direction, but that the winding is divided into sections which are wound alternately clockwise and counter-clockwise. Thus, if the current enters at the bottom, the iron partitions between the sections (shown white on the figure) will have the polarity indicated by the letters N_1, S_1, N_2, S_2. Intermediate partitions, such as A, B, etc., will be non-magnetic and preferably of incombustible and insulating material.

The system takes its name from the fact that the solenoids are enclosed in sheathing of sheet copper, the function of which is indicated in Fig. 1,828. The relative directions of current and magnetic field are such that when

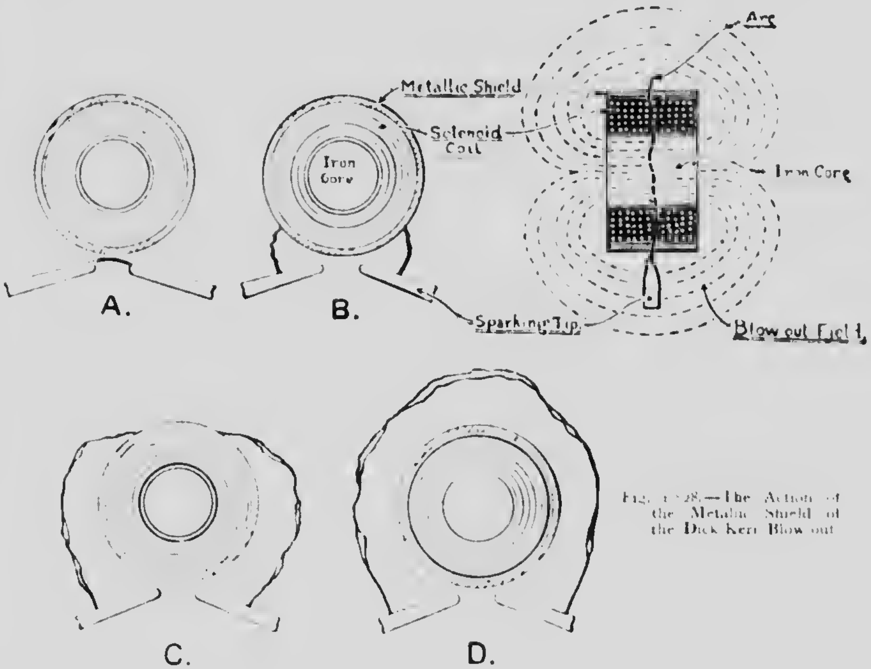


Fig. 1,828.—The Action of the Metallic Shield of the Dick Kerr Blow-out.

a short continuous-current arc is formed as the ring and finger are being drawn apart, this arc is thrust towards the shield as at A, and not in the opposite direction. The arc soon strikes the shield and breaks in two, as shown at B, and by their own magnetic action the two arcs repel one another and sweep round the copper, lengthening very rapidly, as shown at C. If the increasing length of the path has not extinguished them earlier, they will eventually rejoin and encircle the solenoid, as shown at D; but in practice the break comes much earlier, and is made harmlessly on the copper shield. The tendency is also for the arc to travel on the centre of the shield, and thus the partitions are not injured.

An additional safety device worth mentioning is that in swinging back the blow-out solenoids the trolley connection is broken, and therefore the current can only be passed through the controller when the blow-out is closed.

Controller Accessories. To sum up the last few pages, the simple series-parallel controller necessarily consists of a reversing and of an accelerating and traction section, which, as we have seen, are usually on separate barrels operated by separate handles, but with interlocking devices intended to ensure that the operations shall follow the proper sequence.

In addition there is a *blow-out magnet*, the function of which is to diminish the destructive effects of sparking at the contacts when inductive circuits carrying heavy currents are broken. The exciting coil of the magnet is always so placed electrically that any current which passes through the contacts necessarily passes through the coil.

Another addition consists of the contacts for a *magnetic brake*. The principles of working such a brake and a diagram of one method of making the connections have been given, but the mechanical details of the brake itself are postponed to a later section, as the whole subject of braking, and the economical use of brakes, is part of a larger subject.

A still further addition in some controllers consists of contacts for *shunting* parts of the *motor fields* to obtain the highest speeds. Reference is made to this subject in the next section.

In a well-designed controller there should also be *cut-out switches* for disconnecting the circuits of a disabled motor, so that if the disablement occurs, as is most likely, during actual running, the circuits can be quickly rearranged and the car brought to the repair shop by means of the other motor or motors.

Controller Explosions.—Alarming explosions sometimes occur in cylinder controllers whilst in operation. These may be traced either (i.) to careless handling of the controller, or (ii.) to the working parts or ancillary apparatus and wiring of the car not being kept in order, or (iii.) to bad design or defects in manufacture.

The first two causes are most frequent, especially the first. If the handle of the main barrel be turned too rapidly in accelerating, currents much heavier than the controller is intended to carry may be drawn from the supply circuit, and trouble follows. On the other hand, a too slow and timid turning, with the handle held hesitatingly in a mid-position, may give rise to dangerous arcs at the fingers. Similar effects may result if the handle attachment has worn loose, causing the barrel to be in one of these mid-positions when the motorman has reason to assume that the contacts are fully on the step to which he has moved the handle. This, of course, belongs to No. (ii.) class of causes. Running with heavy brake currents, or reversing the car to obtain a quick stop, is also mishandling the controller, and in either case may give rise to serious trouble.

Lack of proper care of the controller and its resistances give rise to trouble in various ways. Thus, if the wearing parts of the contacts are not kept in order or if there be too much oil and grease on the contacts, the conditions for good working are not fulfilled. Also if any considerable proportion of one of the resistances becomes short-circuited, or if a resistance be broken, obvious and troublesome results will follow.

Defects of design may result in a controller being too small for the service or in the resistances being of wrong values relatively to the number of accelerating positions. Faults in the car wiring may at any time lead to excessive currents in the controller.

From the above it will be gathered that although a tramcar controller is a fairly robust piece of apparatus, it cannot be misused with impunity, and with its ancillary apparatus must be kept in proper order if it is to give satisfactory service.

Indirect Control. Most of the troubles just referred to are due to the passing of the heavy power currents through the controller, and to the making and breaking of these currents within the controller. Many years ago, in operating trains of cars as distinct from the single car most usual in tramway service, it was found necessary, for reasons given in the next section and elsewhere, to use remote-controlled switches placed near the motors and operated by quite small current from a master controller under the hand of the motorman. Of late years these methods of remote control have been extended in America to single cars, especially in connection with improved and more rapid methods of handling the traffic. The methods and apparatus for heavy trains are fully described in the next section, and as the principles involved are the same it will be convenient to defer the consideration of the subject for the present.

We give, however, in Fig. 1,829* a diagram only of the connections for a "*modified direct control*" system now widely adopted in America, which relieves the controllor fingers of the heavy arcing and burning incident to the rupture of circuits carrying heavy currents. The power currents from one of the trolley bases T are brought through the main switches M_1 or M_2, and through a fuse F underneath the car to the top contact of the contactor-switch c_1. A separate circuit is taken off through a fuse and switch S_1 to the conductor *a*, also underneath the car, the lightning arrester being Tee-d off this circuit. The controller K, one at each end of the car, is of the usual cylindric type described above, but is provided with an auxiliary contact device at A consisting of two contact fingers operated by a pivoted arm which is actuated by a cam on the controller drum. When the drum is turned in the "on" direction, the main circuit drum fingers close first, and then the control fingers at A. The power circuit is thus closed by the contactor switches c_1 and c_2, which are actuated by a small current drawn by their operating coils from the lead *b*, which, through

* *Electric Railway Journal*, Vol. XLVI., p. 652 (1916).

one of the tripping switches S_2, is made alive by the A contacts. The power circuit is therefore not closed by the main drum fingers in the controller, and when the drum is turned in the opposite direction the auxiliary contacts a open before the main circuit drum fingers, and the power current is broken at c_1 and c_2 instead of inside the controller. It should be noticed that the tripping coil of S_2 is in the power circuit, so that if an excessive current passes S_2 opens, the contactors c_1 and c_2 follow, and the power is cut off. Currents may also be drawn from a and b to operate contactors for the "transition" period between series and parallel, when also the arcing in the controller may be serious, and thus the controller is relieved of all heavy duty, and its reliability is greatly increased.

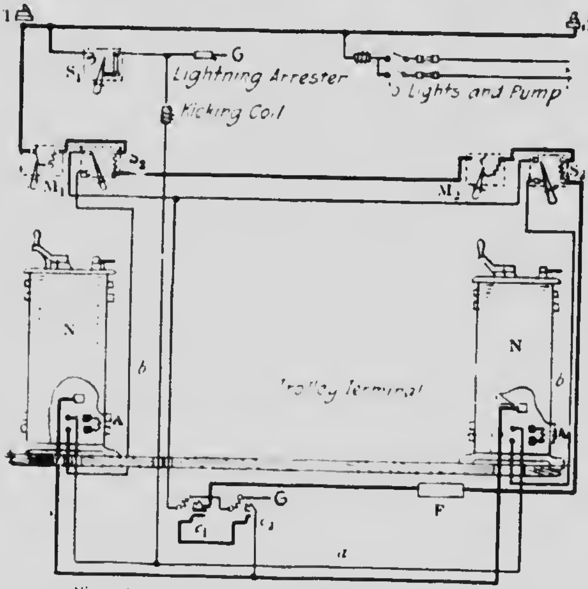


Fig. 1,829.—Connections for "Modified Direct Control."

This type of control also renders possible the interlocking of the control

Fig. 1,830. Typical Modern American Tramcar.

system with door opening and closing, and other safety devices. For instance, a break or breaks may be arranged in the a b circuit of Fig. 1,829, which is only bridged when all doors are tightly closed. The motorman, hen the car stops and the doors are opened, can set his controller to the starting position, when the car will start ahead without any signal from the conductor on all doors being closed. The use of the *emergency brake* may also be arranged to open the *a b* circuit, thus taking off the power as well as setting the brakes, stopping the car more rapidly, and having other advantages.

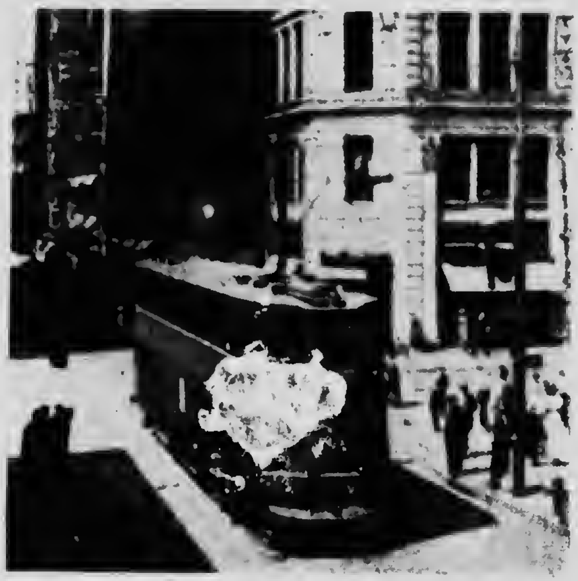


Fig. 1,831.—Double-decker American Tramcar.

A modern American car is shown in Fig. 1,830. It has separate entrances and exits, and is of the single-deck type which is almost of universal use in America as against the double-deck cars which are common in this country. Double-deck cars are, however, not unknown there, as is shown in Fig. 1,831, which is a view in Pittsburgh on a route on which the traffic is heavy, but on which only a few stopping points are allowed.

II. C.C. POWER CONTROL ON RAILWAYS

We now pass to some of the methods of controlling electric power on *trains* operated by C.C. and by A.C. motors. There is no section on A.C. working of tramcars, because modern tramcars are practically all operated by continuous-current motors whatever the form in which the electric power is originally generated and distributed. In this chapter we are dealing with the control of the power on the moving vehicle itself, and not with its control in generation and distribution, which has been dealt with in preceding chapters. We commence with the control of C.C. power.

The methods in use with continuous-current railway motors for starting, running, reversing, and other necessary operations in practical work follow closely for light trains those used in tramway service, but for heavy trains with numerous vehicles it has been found desirable to modify them in detail, though the main principle of series-parallel control is still maintained. The principle of such control has already been fully described as applied to the two motors on ordinary tramcars (*see* pages 1633 to

1638), and may be briefly stated to consist in putting the motors in series for starting and low speeds, and then switching them into parallel for the highest speed. This principle can obviously be extended to higher voltages, and to four or eight motors, provided the large current which may be necessary for so many motors in parallel, can be handled by the controller.

Series-parallel Control. A good example of the series-parallel control of four railway motors placed upon a single locomotive is furnished by the system adopted on the locomotives originally employed on the

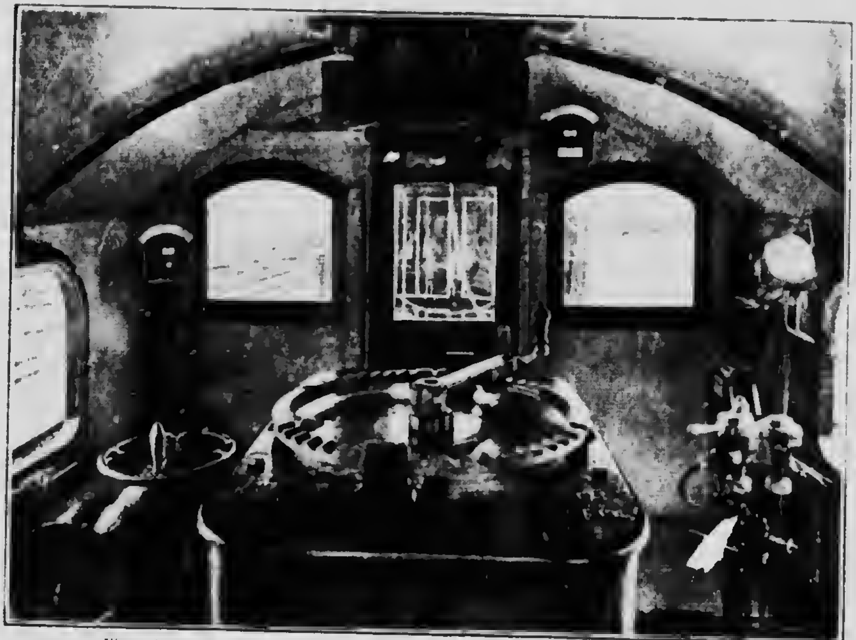


Fig. 1,832.—The Driver's Cab and the Controller, Central London Railway

Central London Railway, and described at page 1614. The driving equipment of the locomotive in this case consisted of four 175-H.P. motors, requiring at full load a current of 1,330 amperes at 500 volts. The motors are operated in pairs, each couple of motors being permanently connected in parallel, and treated as a single unit for control purposes. For starting, the two sets are joined in series on the controller, and the subsequent manipulations are those of the ordinary series-parallel control of two motors, but the modification of the details consequent upon the different conditions, as compared with tramway service, are of interest.

The controller was of the cylinder type, and stood, as shown in Fig. 1,832, in the middle of the driver's cab. It was of much heavier construction [illegible] ordinary [illegible] controller and [illegible] notches, there being nine positions for [illegible] running and [illegible] for parallel

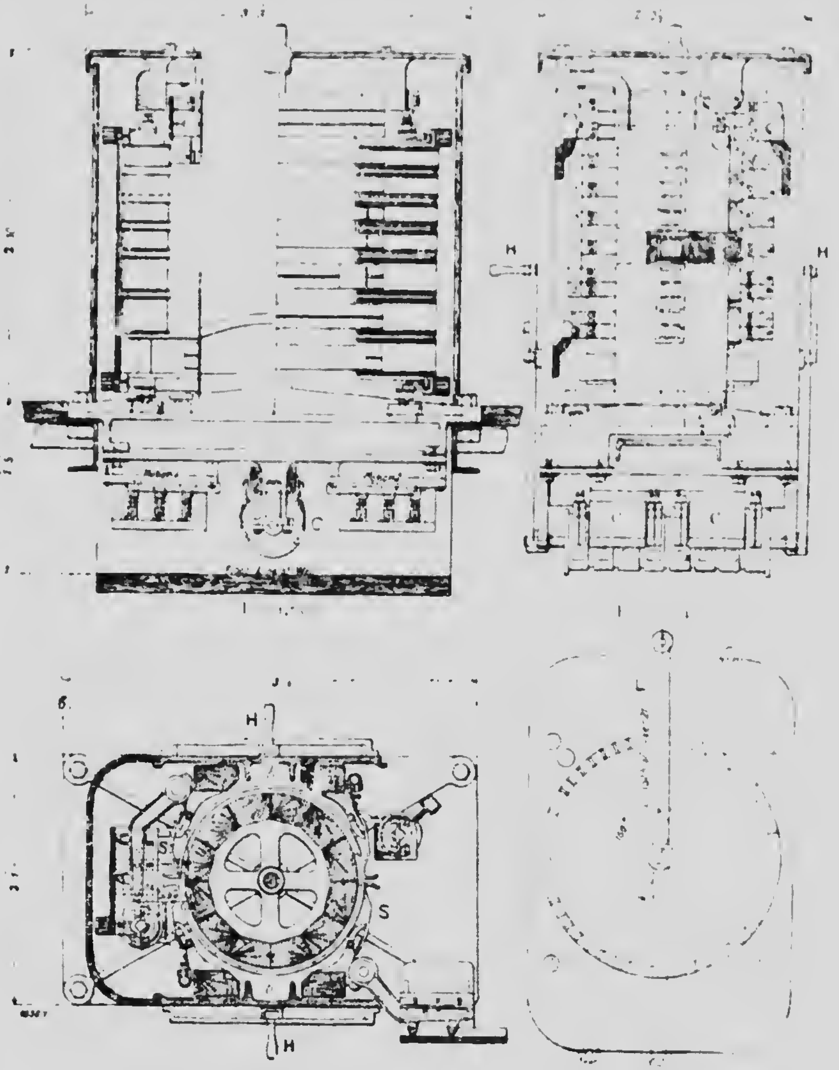


Fig. [illegible]

[illegible] Controller used on Early Locomotive of Central [illegible] Railway [illegible]

running. Three sectional and one top view of the controller are given in Figs. 1,833 to 1,836; of these Figs. 1,833 and 1,834 are vertical sections at right angles to one another and showing different details in the two halves of each diagram. Fig. 1,835 is a horizontal section through the movable cylinder and a set of the fixed contacts, and Fig. 1,836 is a plan of the top plate showing the rotating lever and the positions of the notches. The power cylinder was built up of specially treated hard wood, a material not now used in good modern controllers. Upon this wooden cylinder were mounted contact bands *bb* (Fig. 1,835) of hard copper of varying lengths, against which the fixed springs *ss* pressed. Opposite each contact finger there is a magnetic blow-out to extinguish any arc which may tend to form on break.

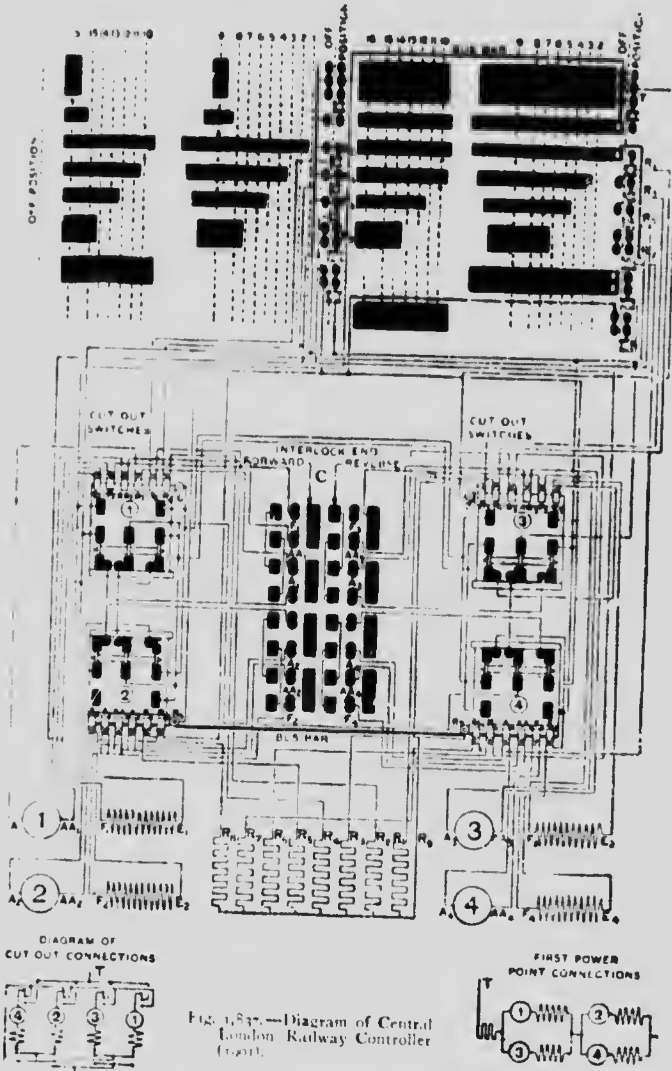


Fig. 1,837.—Diagram of Central London Railway Controller (1901).

These fixed contacts are in pairs at opposite ends of a diameter of the cylinder, and therefore in the developed diagram of the connections which is given in Fig. 1,837 they are indicated by two vertical columns of black dots, the bands on the cylinder being represented by the black rectangles. The broad bands at the top, opposite no fewer than three pairs of contacts testify to the heavy currents to be handled. An examination of the arrangement of these rectangles between the last series position and the first parallel position shows that at one point in the transition period (after the controlling resistances have all been reinserted) there is a complete break in the connections, and therefore the transition method adopted corresponds generally with that shown diagrammatically in Fig. 1,817 (page 1565).

The main controlling handle was a lever L (Fig. 1,836), 21 inches long, working over substantial notches and provided with a ratchet arrangement. There were two interconnected reversing handles R R (Figs. 1,834 and 1,835), one at either side, so that one should always be within reach of the driver. The reversing cylinder C (Figs. 1,833 and 1,837), instead of being at the side and vertical as usual, was underneath and horizontal, though for convenience in the diagram (Fig. 1,837) it is shown at C with its axis parallel to the axis of the other cylinder. The four blocks of contacts marked (1), (2), (3) and (4) on either side of this diagram are the cut-out switches, one block for each motor; a simplified diagram of their connections is given at F. With these explanations the reader should have no difficulty in tracing the connections. The reversing and controlling axles had the usual interlocks, which have been explained elsewhere (see page 1628), to prevent accidents happening by wrong combinations of their respective positions.

Heavy-current Controllers.—The modifications of the ordinary two-motor cylinder controller to adapt it for this heavier work will be realised by comparing the Dick-Kerr controllers illustrated in Figs. 1,838 and 1,839 with the corresponding two-motor controllers previously described. In Fig. 1,838 the controller illustrated is Messrs. Dick, Kerr & Co.'s standard pattern for four 100 H.P. motors. The full mechanical output of one set of such motors is 400 H.P. or 300 kilowatts. Allowing a working efficiency as high as 90 per cent., this means an electrical input of 330 kilowatts, and therefore a current at 500 volts of 660 amperes, though in practice a somewhat higher voltage, and therefore a correspondingly smaller current, may be employed. To handle these very large currents it will be noticed that the contact plates on both the power and the reversing barrels of the controller present wide surfaces to the contact fingers, and that the latter are split up, like the collecting brushes on a dynamo, into groups of narrow fingers in parallel, thus ensuring, as in the dynamo, flexibility of contact and facilitating the renewal of the working contacts on the individual fingers. The controller is provided with the metallic shield blow-out solenoid already described (see page 1644), which is shown thrown back in the figure so as to expose to view the contacts of the power cylinder. The reversing cylinder, besides the usual forward and reverse running positions, has also positions for cutting out any pair of motors, the remaining pair being controlled in series and parallel as before.

A still further development is illustrated in Fig. 1,839, which shows standard Dick-Kerr controller for eight 160-H.P. motors or 1,280 H.P. in all. In this case, however, there are two power cylinders with four motors on each. These cylinders are geared together so that they can be operated simultaneously by one crank handle. The reversing barrel is behind and carries contacts, and has positions similar to those just described for the four-motor controller. There are, of course, two blow-out solenoids with their separating partitions which are again shown thrown back so as to expose the working contacts. This and the preceding controller Fig. 1,838 are used on the Lancashire and Yorkshire Railway, the controller in Fig. 1,839, at the voltage used, dealing with currents up to 2,500 amperes, a severe test of the efficiency of the blow-out arrangements.

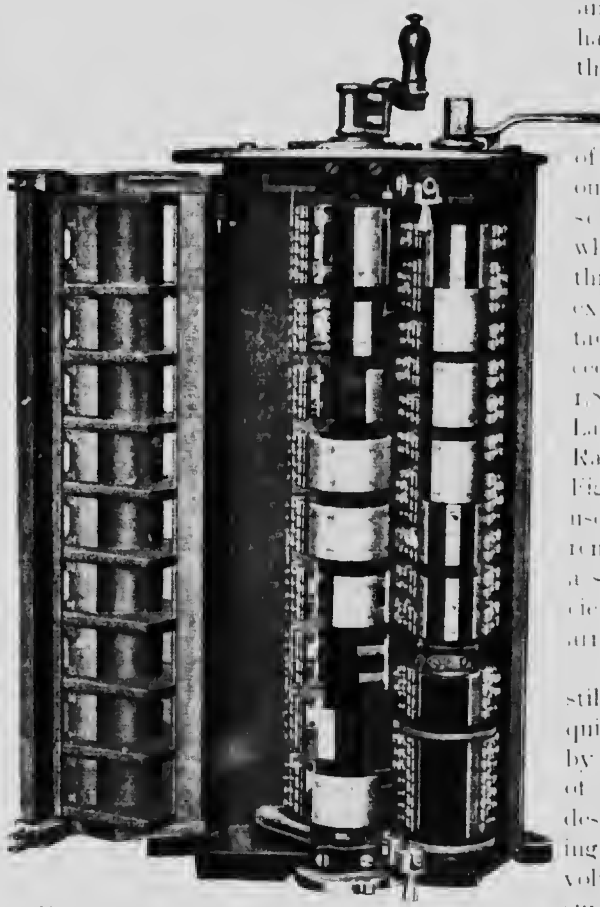


Fig. 1,838.—Dick-Kerr Controller for Four 100-H.P. Motors.

In *heavy railway train* still higher power is required, as will be evident by a reference to some of the large locomotives described in the preceding chapter, and with the voltage unchanged the currents will be correspondingly higher and more difficult to manage on a C.C. controller of the cylinder type. The question of collecting all the power on a locomotive or of using separate motors applied to numerous axles along the train has been discussed in Chapter XVI (see pages 1500 *et seq.*), and to secure the advantages of the latter resolves itself into the problem of controlling from a single point the currents which have to be supplied to the separate motors at the different speeds. If this problem can be satisfactorily solved from the practical standpoint, then the necessity for separate locomotives for [illegible] working disappears, except in certain cases which have already been referred to.

[illegible] Multiple-Unit Control

The practical solution lies in some system of multiple-unit control, by which is meant that, regarding the motors on any single carriage as a unit, all such units contained in a long train must be controlled simultaneously from any convenient position on the train without the heavy power currents being transmitted through couplings from one carriage to another. In practice it is not found necessary, in obtaining the advantages described, to make every wheel a driving wheel, which would be the extreme case. It is not even necessary to

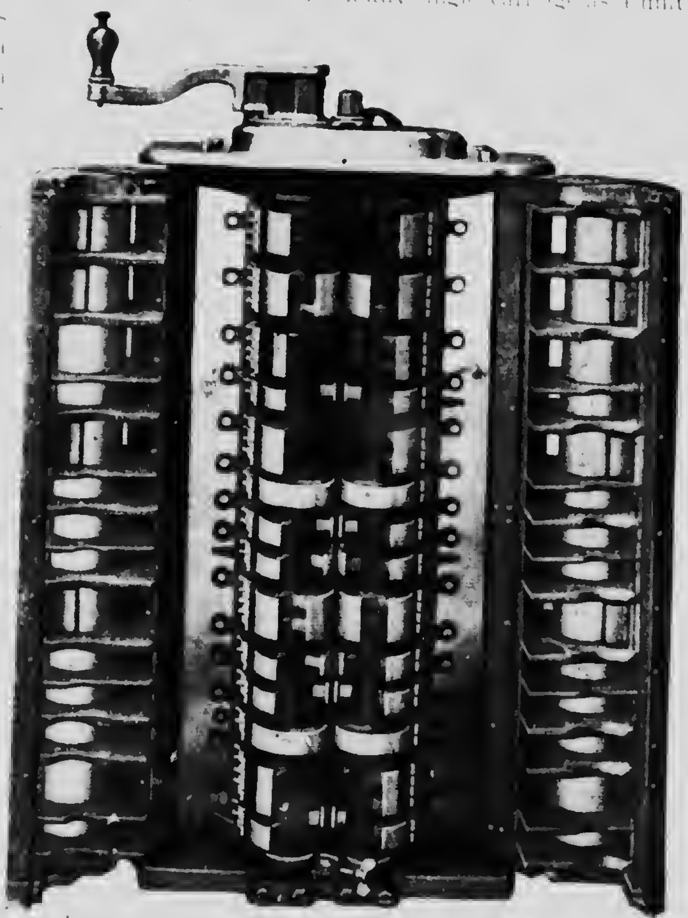


Fig. [illegible]. Dick-Kerr Controller for Eight [illegible] h.p. Motors (Magnetic Blow-out Solenoids thrown back).

have motors on every coach, trains being most frequently made up of motor coaches and non-motor coaches or trailers, as they are called, and even then it is usually sufficient to have two motors only on each motor-coach.

An obvious solution is to place on each motor-coach in some convenient position, an ordinary series-parallel controller, and apply to the latter some electrically controlled mechanism to take the place of the human agent. The currents for controlling such mechanism can obviously be low-voltage and small currents carried from coach to coach by light, insulated conductors, which can run the whole length of the train and which offer no serious difficulty at the couplings. In addition, it is, of course, necessary that each motor-coach should be provided with the proper picking-up gear for drawing energy in the form of large currents from the live supply conductors.

Such a system was worked out in full detail by the Westinghouse companies, and was used for some years. The forces necessary to rotate the controller barrels were supplied by pneumatic cylinders, which obtained energy from the compressed air installed for other purposes on the train.

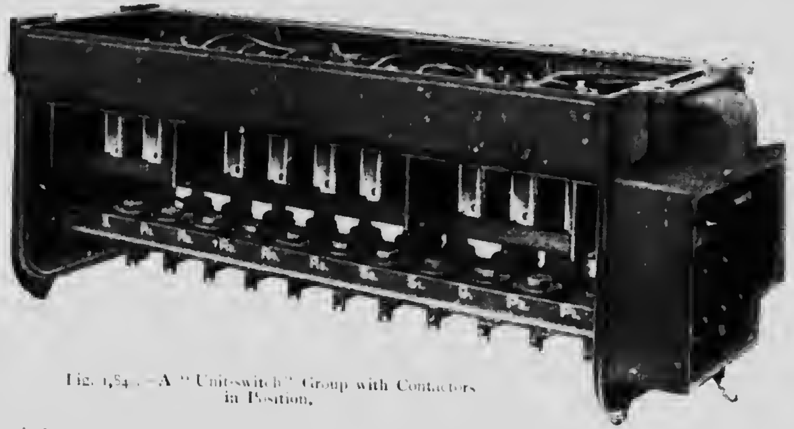


Fig. 1,84.—A "Unit-switch" Group with Contactors in Position.

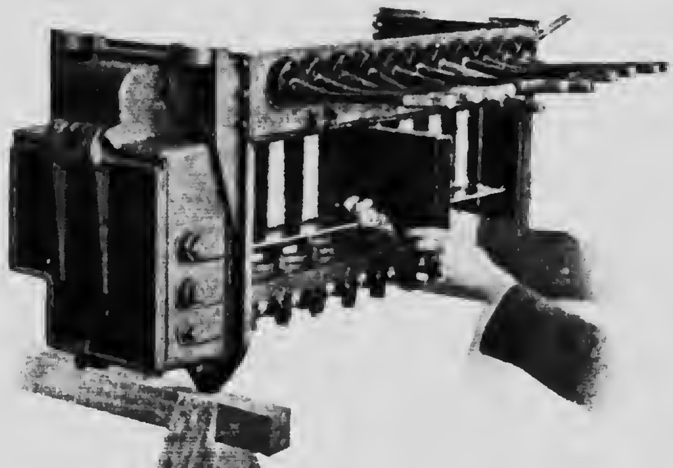
The inlet and exhaust ports of the cylinders were needle valves controlled by electro-magnets, the currents for working which were obtained from a 14-volt battery, the necessary switching being done at a small *master controller*, of which there was one on each motor-coach. The nine conductors required for the various controlling circuits ran the whole length of the train through simple couplings between each coach, and the master controller on any motor-coach could be used to control the whole of the motors on the train.

Simultaneously other systems were worked out in which the necessary changes were made by a series of make-and-break switches, known as "contactors," the working parts of these switches being actuated directly or indirectly by electro-magnets, which do not require heavy currents to be passed from coach to coach. The Westinghouse companies have replaced the system referred to in the last paragraph above by a system of this kind, which will now be described.

The Westinghouse Electro-pneumatic System.—A recent form of this system, whilst employing "contactors" instead of cylindric controllers so far resembles the original system that the contacts are opened and closed by compressed air operating on pistons in little pneumatic cylinders, the inlet and outlet valves of which are operated by electromagnets receiving currents from a 14-volt battery and controlled by a master controller placed on any of the motor coaches of the train. Each motor coach is, as a rule, provided with a master controller at each end, and carries the battery from which the control currents for the whole train are taken when the train is being controlled from that particular coach.

Fig. [illegible] A Rev[illegible] [illegible]

The contact makers and breakers for the series-parallel control of a pair of motors or of four motors arranged two and two in parallel are contained in a standard frame of which a view, with the "contactors" in position, is given in Fig. 1[illegible] (p. [illegible]) which forms what is technically known



F[illegible] Westinghouse "Switch Group" [illegible] of Contactors as a "unit-switch group." This group with its eleven contactors, replaces the main operating barrel of an ordinary series-parallel controller. The place of the reversing barrel is taken by a separate contactor, which is shown in Fig. 1,841. The contact strips which are to make the connections for the two motors or two groups of motors are carried by a central plunger made of insulating material, which is on the piston-rod of the pneumatic cylinder at the top of the case. This plunger corresponds to the barrel of the cylinder reverser, and carries the strip conductors at four different levels. These conductors make contact with the fixed flexible jaws, to which the heavy leads for the motor currents are run. In the highest position of the plunger the current is sent to the armature in one direction, whilst in the lowest position the current to the armature is reversed.

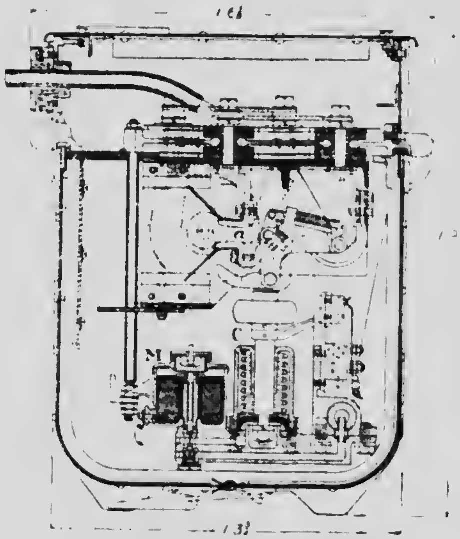


Fig. 1,843.—Cross-section of a Switch Box.

The switches in the frame (Fig. 1,840) are compactly designed, with a view to interchangeability and replacement in the event of injury, as shown in Fig. 1,842, which shows the contact box of one of the contactors being removed from a somewhat similar frame. The details of a switch group for one position in the frame are given in Fig. 1,843, in which are marked the over-all dimensions, from which the reader can realise the size of the apparatus. In this figure C is the pneumatic cylinder below the piston of which pressure air can be admitted by the valve immediately below the plunger of the solenoid electro-magnet M. The valve when lifted connects the two horizontal pipes, the lower of which is supplied with compressed air from a reservoir. When, therefore, the solenoid is energised and the armature sucked upwards, the upper pipe, which was previously open to the outer atmosphere, has the connecting valve closed, and instead conducts compressed air to below

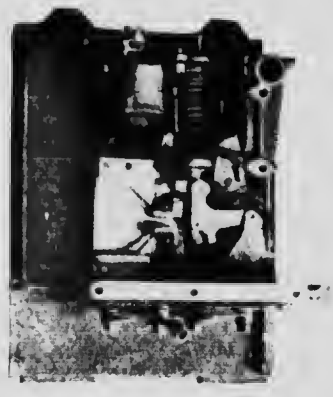


Fig. 1,842.—The "Contactor" in its Box.

the piston in the cylinder c. The piston is driven upwards, and the piston rod through the link motion above forces the lower of the two jaws at a against the upper with a rubbing contact at the moment of closing, thus keeping the contact surfaces clean. A photograph of the box with some of the parts removed and the pneumatic cylinder and the valve chamber cut open to expose the working parts, is given in Fig. 1,844, which should be compared with Fig. 1,843.

The valve chamber is shown in section on a larger scale in Fig. 1,845, in which it will be seen that the upper or exhaust valve *a* and the lower or inlet valve *b* are mounted on the same spindle, and that their travel is very slight. The armature A of the electro-magnet is pulled downwards when the current passes, forcing the top valve on to its seat and opening the bottom valve, simultaneously compressing the spring s which forces up the valve spindle when the current ceases to flow. E is the exhaust port, C the passage to the cylinder, and P the pipe for the supply of compressed air.

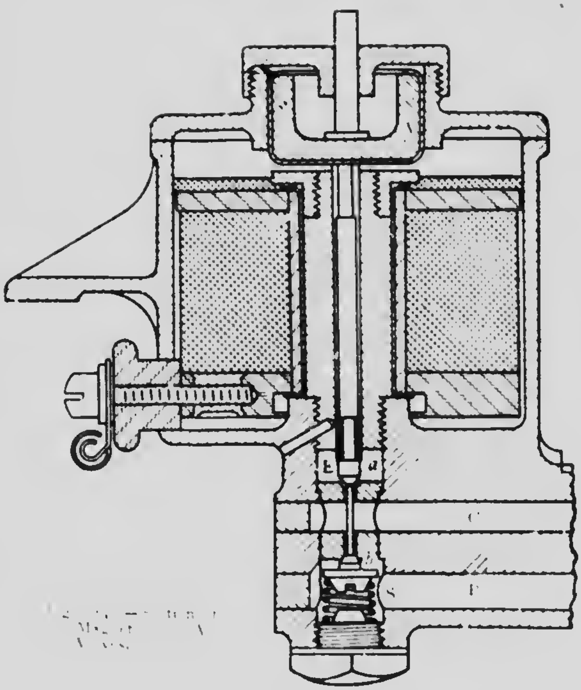


Fig. 1,845.—Section of Magnet Valve.

In moving upwards the piston, which is indicated by a thick black line in the diagram in Fig. 1,843, compresses the powerful cylindric spring shown in section with a force of about 100 lbs. As soon, therefore, as the solenoid loses current, allowing the valves *a* and *b* (Fig. 1,845) to drop back, shutting off the pressure air and placing the space beneath the piston in communication with the atmosphere, this compressed spring forces down the piston, and the lower jaw at *a*, Fig. 1,843 is pulled down with considerable force, thus breaking the heavy current circuit.

The magnetic blow out is particularly interesting. It is indicated by the dotted circles close to the contact at *a* in Fig. 1,843, but is shown more completely in Figs. 1,846 and 1,847. The blow out magnet is in two parts which are placed one on either side of the jaws *a* (Fig. 1,845). Each part is in a shallow box, which is shown complete in Fig. 1,846, and with one side cut away in Fig. 1,847. An inspection of these figures will make it evident that, with the blow-out coils fully energised, a magnetic field is set up across the space occupied by the jaws. This field is so powerful that any arc set up on breaking the circuit at these jaws will be blown out by the action which we have described elsewhere.

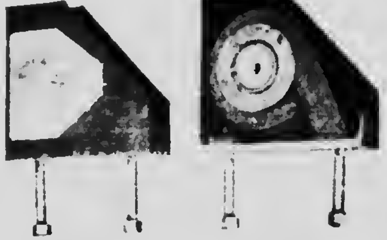


Fig. 1,846. Fig. 1,847.
Details of "Blow-out" Magnet.

The master controller is of the cylindric type with contacts on either side of the cylinder. It is shown in Fig. 1,848, alongside an ordinary cylindric controller made by the same firm. It will be noticed that the

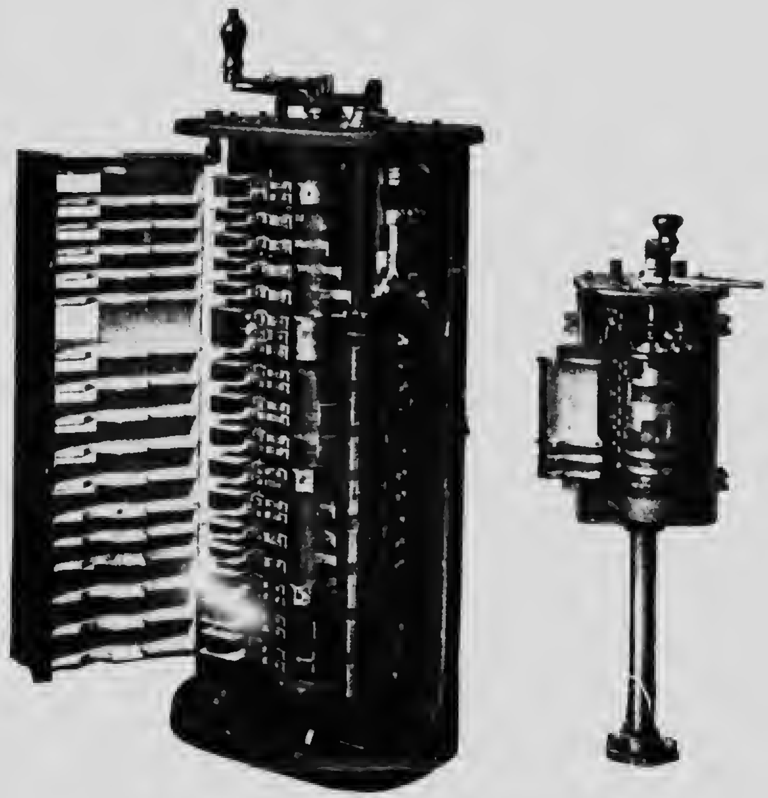
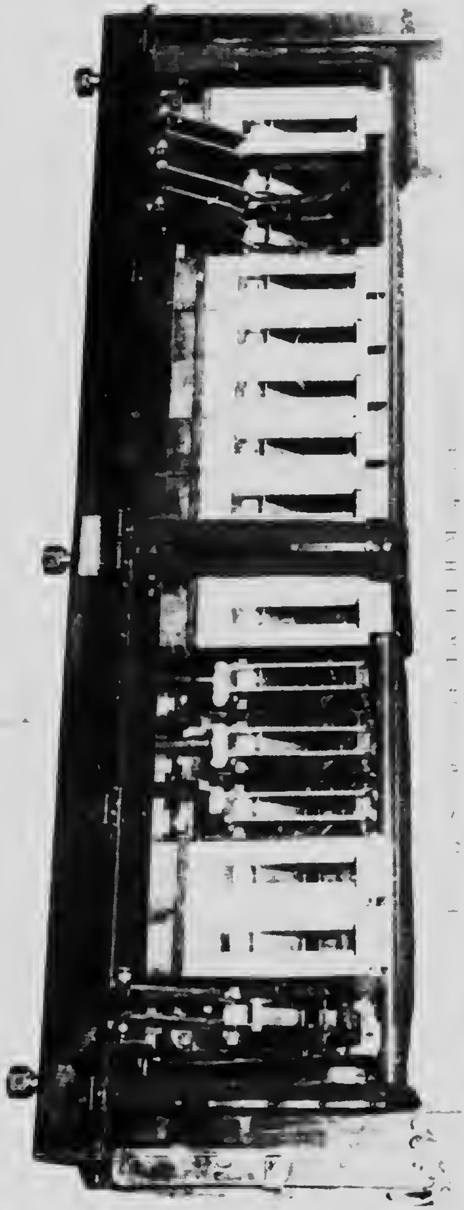


Fig. 1,848.—Westinghouse Ordinary Controller and Unit-switch Master Controller.

master controller is quite small, as it has only to handle a 14-volt current and that it has nine working positions, five with the motors in series, and four with the motors in parallel.

The battery controlling currents are obtained from one of two 7-cell secondary batteries carried on each motor-coach. The leads from these batteries are brought to a small switchboard, from which one battery is connected to the master controller, and the other, in series with the car lamps, is put across the mains so that the current for the lamps passes through it as a charging current, a device which whilst utilising the 500-volt circuit, avoids the waste of energy by useless resistances in the charging circuit. By a simple throw-over switch, the two batteries can be interchanged on these alternative circuits.



The British Thomson-Houston Multiple-unit System. This system, though developed much earlier, and first known as the Sprague system, is designed upon the same lines as the system of "contactor control" for continuous-current motors for ordinary factory or other working, already fully described (see Vol. II., Section I., pages 674 *et seq.*). The necessary contactors are energised in the first instance by shunt current bridged across the full voltage of the supply circuit, too rapid speeding up being guarded against by the action of a current-limit relay.

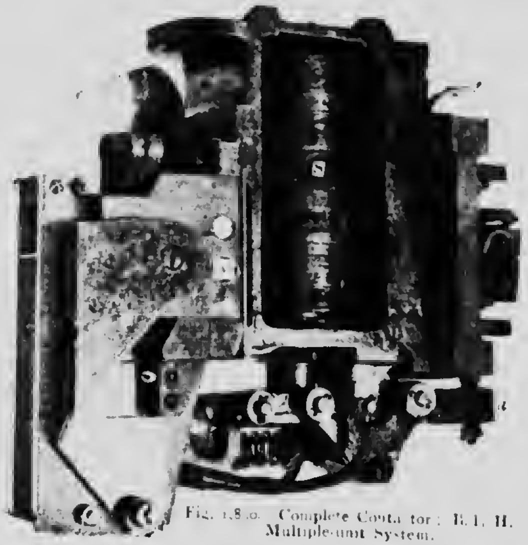


Fig. 1,850.—Complete Contactor: B. T. H. Multiple-unit System.

In the multiple-unit system for railway working the conditions are more complicated than those described for single motors, since arrangements have to be made for the change from series to parallel connections of the motors as well as for reversing. The contactors also have to be carried on the coach instead of on a fixed stationary board, and therefore, as they will be subject to continuous vibration and to spasmodic and violent jolts, they cannot be of the type described for ordinary fixed panels for motor working.

Fig. 1,851.—Front View of the Contactor

The contactors used, instead of being mounted on such a panel, are arranged side by side in a contactor box as shown in Fig. 1,849, this contactor box being placed underneath the car or coach. When more convenient for the conditions of service, this box can be divided into two, which are placed back to back. In this equipment, which is the standard main equipment, there are fifteen contactors for each motor-coach, in addition to a separate circuit-breaker and a separate reverser. In Fig. 1,849 some of the contactors (4, 5 and 6, counting from the left) are shown with their front guard plates removed, and others (1, 13 and 14) with their arc-chute plates thrown up on their hinges, thus exposing the main contacts for cleaning and repairs.

An individual contactor is shown in Fig. 1,850, in which S is the magnetising solenoid. The contactor as viewed from the front is shown in Fig. 1,851. The contact jaws can be seen in the central chamber, and at the sides are the recesses for the blow-out coils. The plunger of the solenoid s (Fig. 1,850), acting upon the heavy link motion, brings the movable lower contact up against the fixed contact with a wiping movement which ensures the rubbing of the contact surfaces against one another, thus tending to keep the metallic contact in good electrical condition.

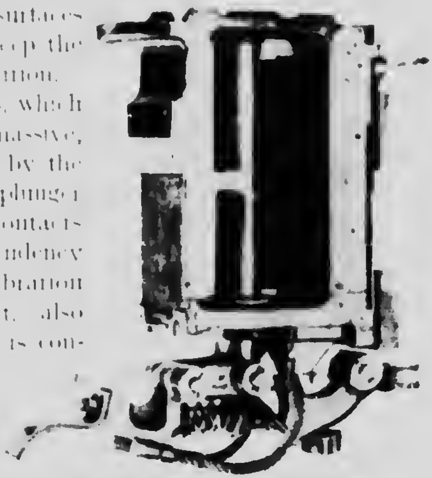


Fig. 1,852.—Plunger and Magnetic Circuit.

The plunger and the movable parts, which are shown separately in Fig. 1,852, are massive, and when the shunt circuit is broken by the action of the control operations, the plunger and its attached masses fall, and the contacts open by the action of gravity, any tendency to stick being counteracted by the vibration of the train. The blow-out magnet, also shown separately in Fig. 1,853, which is contained in the box M (Fig. 1,850), has its coil in series with the fixed contact B, and is therefore energised so long as a current is passing between the contact plates.

The circuit-breaker is very similar to one of the ordinary contactors, but is provided with a brush contact and auxiliary contacts to prevent arcing at the brushes. Moreover, it has two operating coils, one, as in an ordinary contactor, for closing the contacts (which, however, are held closed by a latch), and the other coil for tripping the latch and opening the circuit-breaker.

Fig. 1,853.—Blow-out Coil.

From the circuit-breaker two paths lead to the power circuits of the motor coach, the arrangement of these circuits and the contactors being shown diagrammatically in Fig. 1,854. In this diagram the fifteen contactors are numbered in the order, from left to right, in which they are fixed in the contactor box (Fig. 1,849). The two power leads are taken from the circuit-breaker CB to the fixed contacts of No. 1 and No. 7 contactor respectively, whence the circuits proceed as depicted in the diagram, in which all the contacts are shown open. When any particular contactor closes, the gap in the diagram is bridged, but otherwise it remains open. The contacts are closed by the control shunt circuits, which are not shown in this diagram, and which are somewhat complicated, as there are electrical *interlocks* on most of the contactors designed to ensure, by the action of the relay to be described presently, the completion of each step before the next is made. This is necessary, because the greater part of the control is automatic, for the master controller has only four positions, although the necessary changes are made in thirteen steps, twelve running and

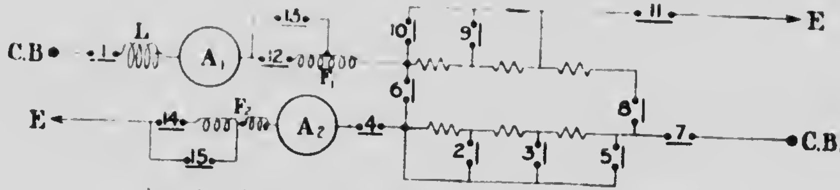


Fig. 1,854.—Power Circuit Connections, B.T.H. Multiple-unit System.

one transition. The combinations of the contactors for the different steps are given in Fig. 1,855 in the form of a table, in which the closing of each contactor is indicated by a black circle, the empty squares indicating that the corresponding contactor is open. The reader should compare these combinations with the diagram in Fig. 1,854, and with the diagrams Figs. 1,816 to 1,819, for series-parallel working, which they generally follow. Thus in the first "step" contactors 1, 4, 8, 12 and 14 are closed, the first two remaining closed during the whole series of operations, for reasons which will be obvious on inspection of Fig. 1,854. The second step closes contactor 2, the third step contactor 9, and so on as shown in the table. The transition step T is specially interesting; on this step it will be found that the combination is different from any of those already given, inasmuch as each motor is bridged by the resistances afterwards put in series with the other motor, and that these two sets are themselves in series. The breaking of the cross link on contactor 6 leaves the two motors in parallel, but each in series with its own regulating resistance.

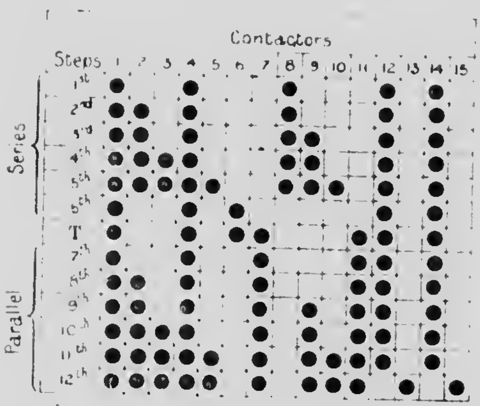


Fig. 1,855.—Scheme of Operation of the Contactors.

The *interlocks* referred to are, in these contactors, placed on the back of the contactor at the right-hand side, as seen in Fig. 1,850. Here there are mounted on insulating bases, as may be more clearly seen in Fig. 1,857 which shows similar devices on the reverser, certain fixed pairs of contacts. These contacts are in the control circuits of the master controller, and may be bridged or open-circuited by the vertical movement of horizontal bridging pieces carried on a spindle attached to the block *a*, Fig. 1,856, which is connected by levers to the plunger of the operating electro-magnet s. When this plunger closes the main circuit jaws of the contactor, it moves the bridging piece in the direction required for interlocking.

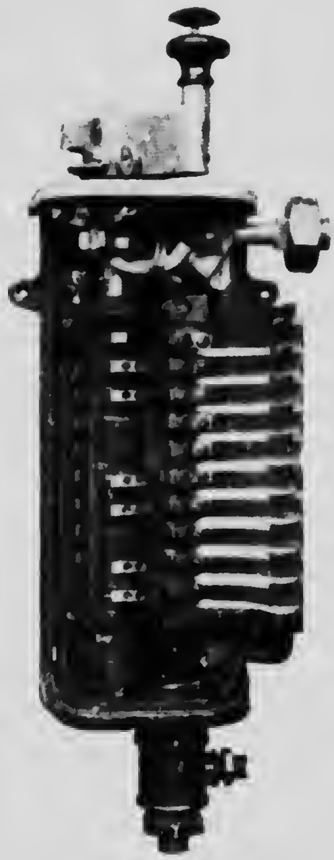


Fig. 1,856.—B.T.H. Multiple-unit Master Controller.

The *master controller* is shown in Fig. 1,856. It is a cylinder controller, with one operating handle and cylinder, the handle being turned in one direction for the forward motion and in the other for the backward motion. When the operator removes his hand from the handle it is thrown immediately back to the "off" position by the action of a spring, against the pressure of which the cylinder is turned by the operator. As already explained, all the control circuits passing through this controller are shunt circuits, and the maximum current at any time therefore does not exceed two amperes. A blow-out magnet is provided.

In whichever direction the controller handle is turned there are only four positions or notches. On the first notch the control current is closed through either the forward or backward solenoid of the "reverser," which is shown separately in Fig. 1,857. The movable part of this switch is a rocking arm carrying the contacts shown closed at the lower part of the figure. At the other end of the arm there are similar contacts, which in the position shown are open. The arm is rocked by two solenoids, one only of which receives current when the controller handle is turned in one direction, and the other when it is turned in the other direction. They cannot both receive current at the same time, and the set of contacts closed determines the relative direction of flow of the currents in the armatures and the series magnet coils respectively, and therefore the direction of the rotation of the armatures.

On the next notch (No. 2) of the master controller, the position of the control circuits is that of the 1st step in Fig. 1,855. The operating coils of contactors 1, 4, 12 and 14 are in series, and so remain until the last steps is reached when 13 and 15 replace 12 and 14. The next five st[illegible] are automatically completed through the operation of the "current-li[illegible] relay" shown in Fig. 1,85[illegible] This relay consists of th[illegible] solenoids; one of these, t[illegible] central one, has a fixed co[illegible] and is wound with the seri[illegible] power coil 1 shown in Fi[illegible] 1,854, and through whi[illegible] the current of No. 1 motor alwa[illegible] passes. The relay is so set th[illegible] when this coil is traversed by [illegible] dangerously large current it [illegible] lift the movable cores of each o[illegible] the side coils, these cores formin[illegible] part of its magnetic circuit. The movable cores each carry a dis[illegible] which, when its core is not hel[illegible] up, rests upon two contact piec[illegible] bridging the gap between them [illegible] in the motor contactor previous[illegible] described (Fig. 681, page 675) for ordinary motor working. The other two coils of the relay are traversed b[illegible] control circuits, and are so connected that the current of one passes throu[illegible] the contacts controlled by the other; thus, if one solenoid be energise[illegible] the other must be without current. In this way a step-by-step action can be obtained, delayed by the action of the series coil until the back pressure generated by the increasing speed of the motors renders the next step safe. The automatic control circuits are completed by means of the interlock switches attached, as described above, to the contactor frames and operated by the

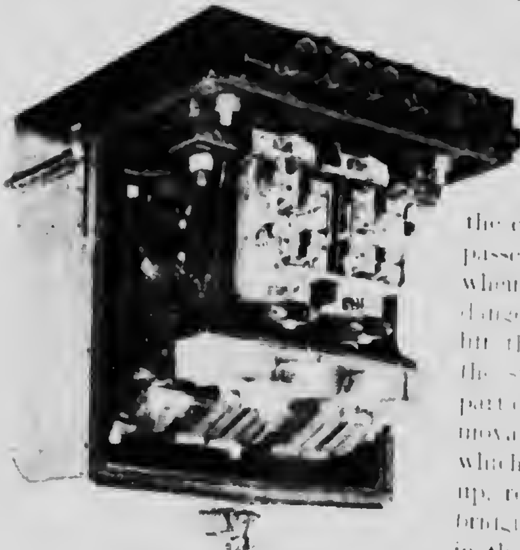


Fig. 1,[illegible].—The Reverser

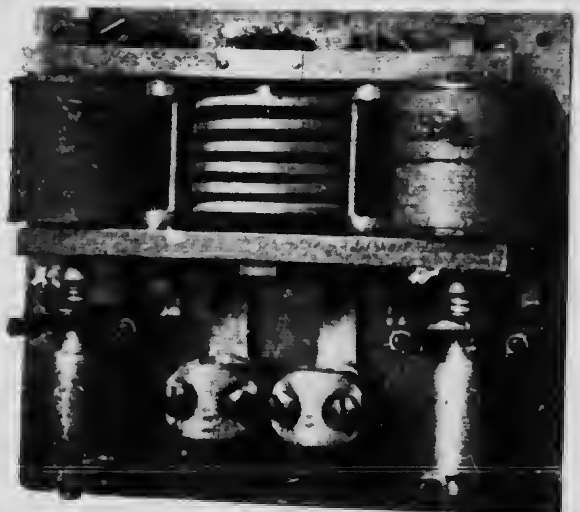
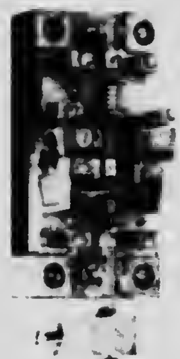


Fig. 1,858.—The Current-limit Relay

movement of the magnet core. They are mounted at the back or right-hand side of the contactor as shown in Fig. 185[illegible]. A better view, showing details, is given in Fig. 185[illegible]. On a vertical pencil four contact discs are mounted and play against fixed contacts, which are above in the cases of discs 1 and 3 (counting from the top) and below for the discs 2 and 4. The vertical pencil is moved by the end of a lever which is part of the link motion operated by the plunger, and when the plunger is down main contacts open, it is pressed up and contacts 1 and 3 are short-circuited. On the other hand, when the main contacts are closed, contacts 2 and 4 are short-circuited.

The first effect of closing a new contactor on any of the steps between the 1st and the 6th is to lift both plungers of the current relay by the excessive current which at first follows the removal of resistance from the power circuit. This, as already explained, interrupts both control circuits and prevent further progression until the main current through No. 1 motor sinks to a predetermined value. The relay then operates through circuits closed on the interlock just described.



[illegible]

When the 6th step is reached the motors are in full series with all regulating resistances out of circuit, and nothing further happens until the master controller is placed on the 3rd notch, when the combination 1 (Fig. 1855) is made by the closing of contactors 7 and 11, setting up the transition stage already referred to. This stage is not allowed to persist, the master controller being quickly moved to the 4th and last notch which makes the combination of the 7th step. From this step to the 12th the current-limit relay takes up the running, and the resistances are removed step by step until the full parallel position is reached on the 11th step.

The 12th step is particularly interesting, as the motors being now in full parallel, further increased speed is obtained by short-circuiting part of the excitation coil, thus weakening the field and necessitating an increase of speed to produce the necessary back E.M.F. to damp down excessive current.

This method of controlling a series-wound C.C. motor by short-circuiting some of the windings of its field magnet coils has been mentioned more than once in the preceding pages, but this is the first time it has been referred to as part of an elaborate system of control. It would therefore appear to be appropriate to give some data here as to the effect of the device on the performance curves of a typical modern railway motor. For this purpose we select the 200-H.P. motor of the General Electric Company, of Schenectady, the performance curves of which are given in

Fig. 1,860, for speed and tractive effort with varying load currents (i.) with full field, and (ii.) with some of the field coils shunted. The motor is a 1,500-volt machine, and the tractive effort and the efficiency are both taken at the driving wheels, the effects of the speed-reducing gear being included. At 200 amperes the motor would be absorbing 300 kilowatts, which is about full load, and the tractive effort is 4,500 lb. at full field, and 3,000 lb. with weakened field. The speed, however, in the first case is only 30 miles per hour, whereas in the second case it is 42 M.P.H., the efficiency in the latter case on these figures being slightly higher. The reader will find it interesting to examine the data for other currents, say for 100 amperes, with which the speed rises to 65 M.P.H. with the weakened field.

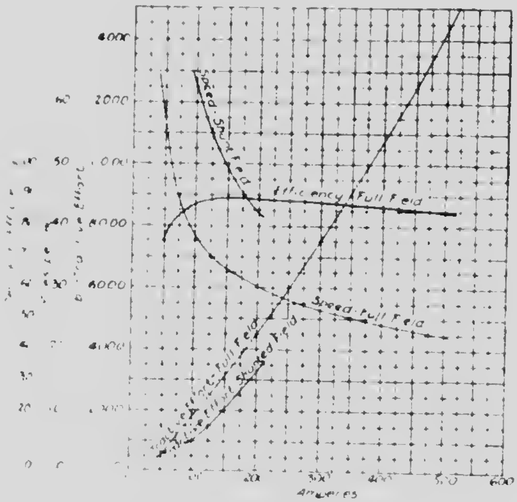
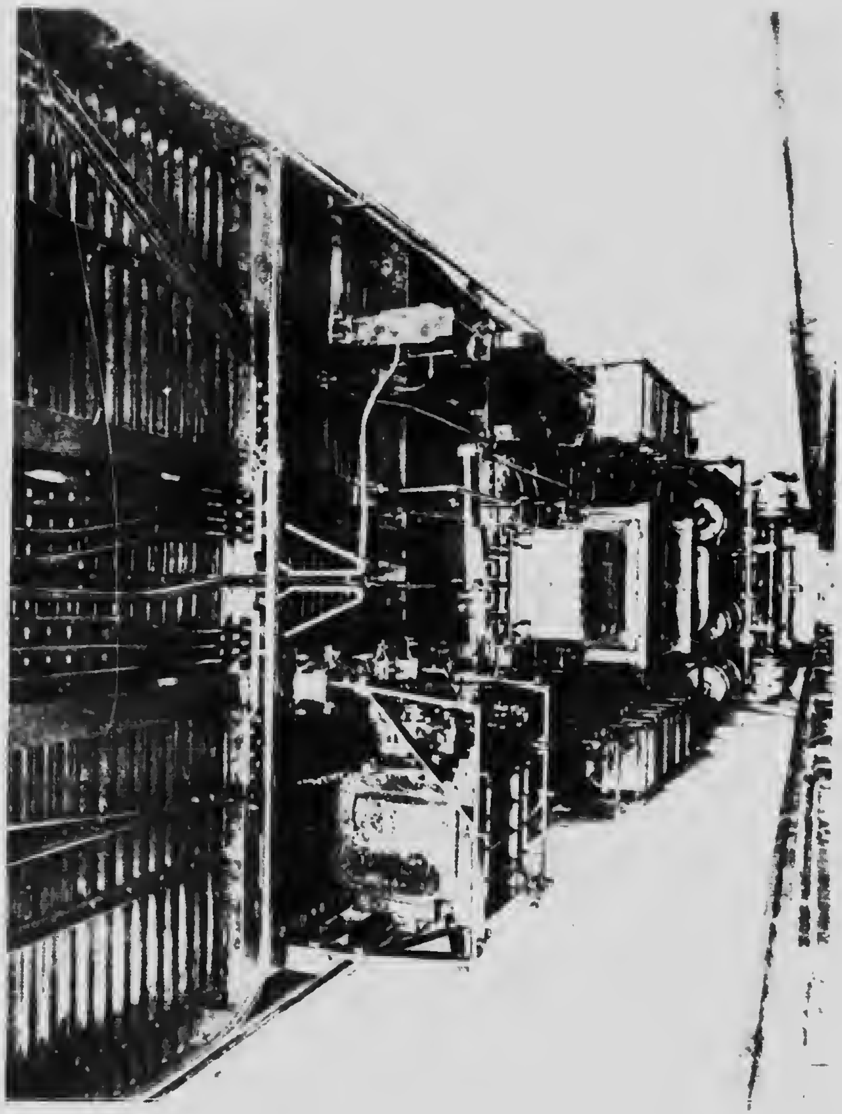


Fig. 1,860.—[illegible]

Returning now to the B. T.-H. controller, the operations so far described require only a five core cable to traverse the train, but two more wires are required for the circuit breaker control circuits, one for the setting or closing circuit, and the other for the tripping circuit. These circuits are operated by a switch placed close to the controller, where there is also another single-pole switch which is used to make and break the connection between the collector and the master controller on the coach where the master controller is being used. The seven core cable, whether coming from the master-controller on the coach, or from another coach, is led through fuses and a multiple switch by which the seven circuits can be simultaneously broken. Special seven point couplings (Fig. 1,861) are used between the coaches, the mechanical parts of the coupling being so designed that the plug and the socket can only be joined up in one position, thus ensuring that the seven circuits are correctly connected up. In addition to the seven core train cable, a twelve core cable is required on each coach.


Fig. 1,861.—Seven-point Coupling for Control Circuits.

With the better commutation now obtainable with interpole motors, higher voltages, as we have shown above, can be used on the supply



circuits, and therefore these control equipments are now being used for a working pressure of 3,000 volts.

The arrangement of the apparatus underneath the coach is shown in Fig. 1,862, which is reproduced from a photograph taken when the coach was over an inspection pit. The contactor boxes are closed, but it is easy to identify the reverser, the main contactor boxes, and the circuit breaker box under the middle of the coach with the resistance frames on either side. The air-brake cylinders can be seen farther forward. They are of course, operated from the driver's position, where also there is a special switch for controlling the pump motor.

The Dick-Kerr Multiple-unit System. The third system to which we shall refer energises its controlling electro-magnets neither from a separate battery nor from shunt circuits on the main-supply leads, but from the series current which has passed through one of the running motors, the electro-magnets being electrically interposed between the motor, and the earth return circuit through the rail. By this means each control magnet only absorbs a very small voltage at nearly earth potential. As in the other systems, the power currents for the motors in each motor coach are drawn from the track conductors and passed back into the return circuit by sliding contacts attached to that coach. Each motor coach is, as usual, provided with two master controllers, one at each end, which when not in use, leave these power connections as described. But when one of the master controllers is being used, it alters the earth connection for No. 2 motor on that coach only, from what may be called the coach earth E_2 to a special earth E_1 (Fig. 1,863) at the ends of the train, where that motor current is earthed after passing through all the control magnets of all the motor coaches other than the one in which the operated master controller is placed. Nine such control circuits run along the whole length of the train, and those which are in use at any particular moment are electrically in parallel.

With this general explanation to assist him, the reader will be able with what follows, to trace out the actual circuits shown in Fig. 1,863, in which the contactor magnets in four groups are represented at the bottom of the diagram, each by a coil and two black square contact blocks. The electrical connections of the coils are, however, for clearness set out separately on the left-hand side, where they are numbered consecutively the magnets being arranged in a different order in the four groups in which each magnet must be identified by its reference number. At the top of the figure is the developed diagram of the controller, which is of the cylindric type, and can be seen in Fig. 1,864, which is from a photograph of the inside of the driver's cab. The controller is shown with its cover removed.

In the diagram (Fig. 1,863) the rings on the two barrels of the controller are represented by light open rectangles, and the fingers by black squares. The lines for the different notches are numbered 1 to 8. The main barrel

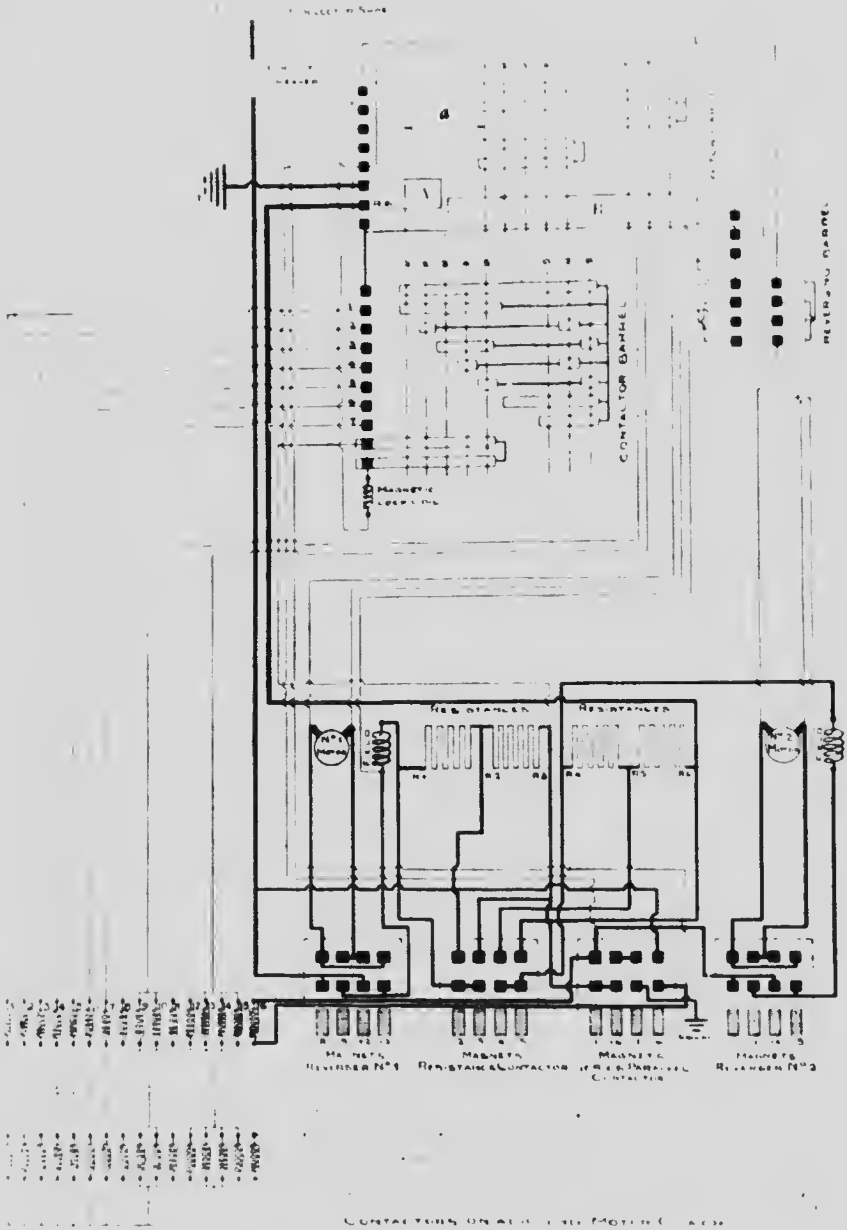


Fig. [illegible] Circuit [illegible] Dick Kerr Multip[illegible] System.

is in two parts, and the upper part has to be turned through the angle indicated by the line *a*, so that the line 1 on it corresponds to the line 1 on the lower part; for further turning, the two barrels move together. The diagram shows the barrel in the "off" position, in which it will be noticed that the seventh finger R 6 is earthed through the ring A. This is the coach earth of No. 2 motor. Before, however, the upper part of the barrel has turned through the angle *a*, finger R 6 is joined to the finger below through the ring B, and any current arriving at R 6, instead of going to the earth T_1, is partly deflected through the upper two rings of the lower part of the main barrel and control circuit and magnet No. 1 to the train earth, and the other part deflected, according to the position of the reverser barrel, into one of the two control circuits operating the reversing contactors 8, 9, 10, 11, or 12, 13, 14, 15 respectively. If the reverser is in the forward position, the required control current reaches R 6 from the finger 1 through the top two rings on the upper barrel, thence to the reverser barrel contacts and the armature, field, and resistances of No. 1 motor, thence through the lowest two rings on the lower main barrel, the "magnetic lock coil," to the 4th and 5th rings on the upper main barrel, thence back to the reverser barrel and through the circuits of No. 2 motor and its resistances to R 6. When, therefore, the controller is on No. 1 notch, and before the contactors close, the position is that the two motors, their resistances, the magnetic lock coil, and all contactor magnets similar to 8, 9, 10, and 11 to the end of the train are in series between the collecting shoe and the tail earth. The contactors 1, 8, 9, 10, and 11 close all along the train, and if the circuits be again traced out it will be found that on each coach except the first the motors are in series with all resistances in circuit between the coach collecting shoe and the coach earth through R 6. The train therefore starts with all motors receiving current and speeds up to the lowest running speed.

The above, the starting case for notch No. 1, has been worked through in detail, but it will be a useful exercise for the reader to trace out the circuits himself for the other positions of the contactor barrel. To guide him it may be mentioned that positions 2, 3, 4, and 5 throw current successively into control circuits, closing the corresponding contactors and short-circuiting the controlling resistances. After notch 5 paralleling begins, and to work out what happens between notch No. 5 and notch No. 6 reference should be made to Fig. 1,863, and the exact position at which the different barrel rings break and make circuit should be noted. The exact method of transition (*see* page 1035) should thus be made out. On notch No. 6 all the motors are in the first parallel position with the controlling resistances in circuit. These resistances are removed in pairs on notches 7 and 8, leaving all the motors in full parallel, and the train running at the highest speed with the controller on notch 8.

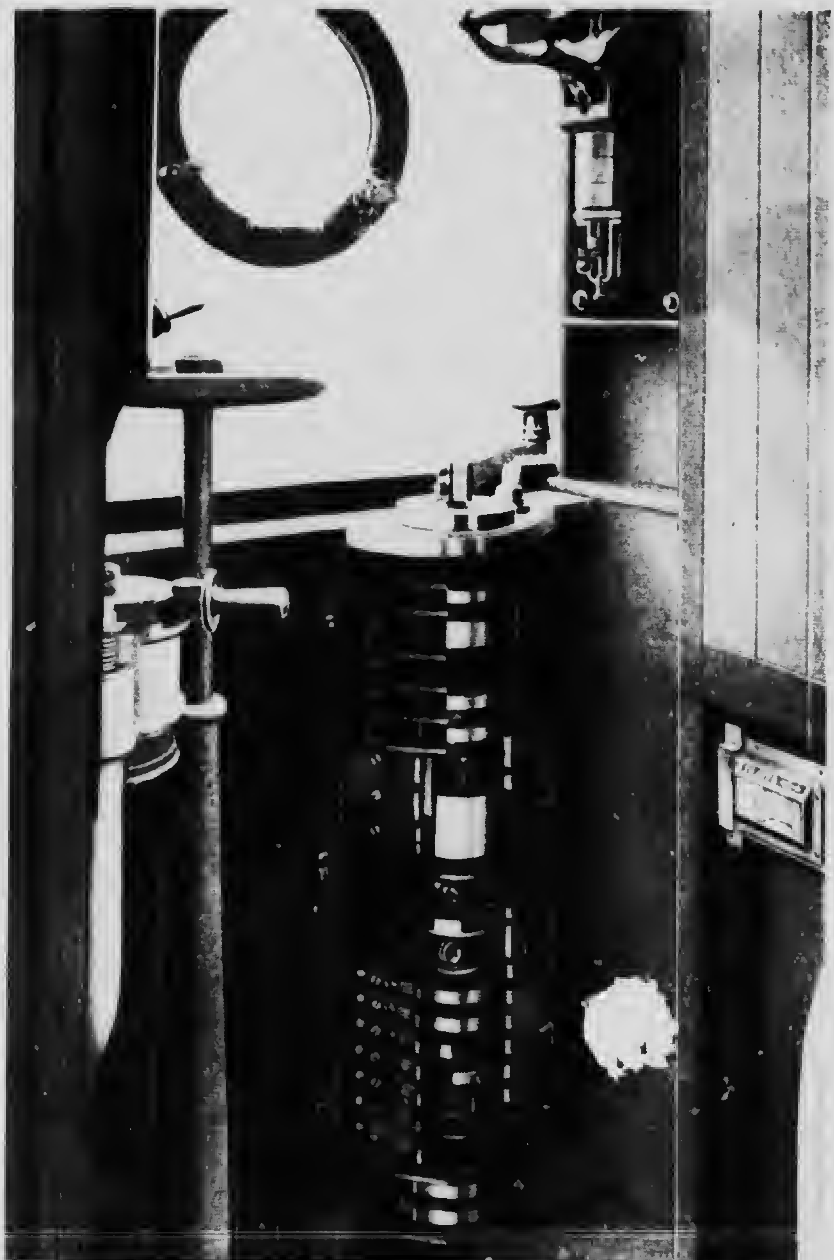


Fig. 1,504. Dick Kerr Master Controller in the Driver's Cab

Views of the contactors are given in Figs. 1,865 and 1,866. Of these Fig. 1,865 shows a group of four contactors with the case closed for working, whilst Fig. 1,866 is the same group with the case opened up by swinging down the blow out coils so as to expose the jaws of the contactors as seen in the upper part of the figure. Fig. 1,867, of which the right-hand side is the front in Figs. 1,865 and 1,866, is a drawing giving a side view partly in section, of a contactor. The switch jaws C and C_1 are mounted on the insulating support D; of these C is fixed on a knife which allows a little play, and C_1 is movable, being operated by the plunger E of the solenoid magnet B, the lower end only of the plunger being shown in the figure. The upper end of the plunger is connected to a lever, which carries C_1. When C_1 in rising presses against C, the latter gives way slightly, causing the two contact fingers to rub lightly, thus keeping the contact surfaces clean.

Fig. 1,865.—Dick Kerr Group of Contactors Closed.

The blow-out coil is shown at G, and is of the solenoid type surrounded by a copper sheath, which is used by Messrs. Dick, Kerr & Co. in their ordinary controllers. Four such coils are shown in Fig. 1,866. They are carried by the carrier framework K which swings, as seen in Figs. 1,866 and 1,867, on the pin at L (Fig. 1,867). When energised, they produce a strong magnetic field in the gap between the jaws C and C_1 as they open. The field has such a direction that the arc formed is blown against the copper sheath H, along which its two ends travel (*see* Fig. 1,828), and if it persists so long, finally breaks harmlessly opposite the opening J. The maximum current for the main contacts is 300 amperes, and the normal current of each solenoid is 10 amperes. The position of two of these contactor frames under the coach is shown in Fig. 1,868; one frame, A, is closed, and the other B, open. The figure also shows the controlling grid-type resistances fixed in position.

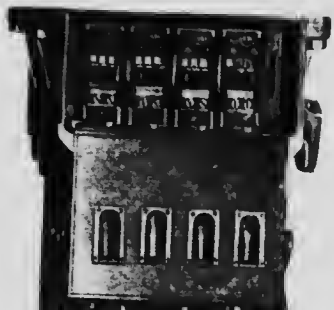


Fig. 1,866.—Dick Kerr Group of Contactors with Guard Shields Swung Down.

When the solenoid of a contactor loses its current, the plunger falls by its own weight and breaks the main circuit. As the solenoids are series solenoids, with a few turns only in the windings, their inductance is small

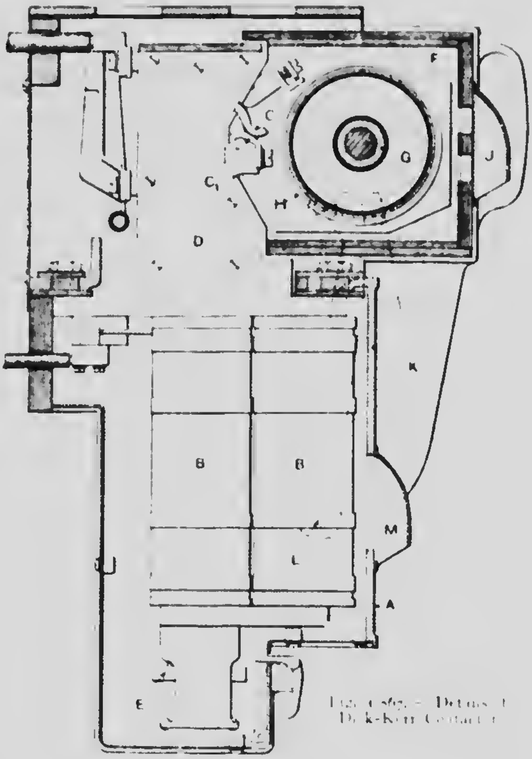


Fig. [illegible].—Details of Dick-Kerr Contactor

and the demagnetisation correspondingly rapid. It is claimed that the plunger is not likely to stick and hold up the contact. The vibration of the coach will, of course, assist. On the other hand, the heavy currents carried by the control circuits render it necessary to design the mechanical and electrical details of the couplings much more carefully than is required by the two preceding systems, but the principles involved are the same.

It will be noticed that the train is as much under the control of the driver as is a tramcar in which an ordinary series-parallel controller is used. In other words, there are no automatic accelerators, but each notch of the controller has a corresponding running speed depending upon the weight of the train and other immediate factors.

Fig. [illegible].—Contactor and Resistance in Position

The system was originally designed for the Liverpool and Southport Railway, and has also been applied to the Liverpool Overhead Railway, the working pressures being 650 volts and 500 volts respectively.

Cam operated Contactors. —The necessity for the existence of an elaborate system of "interlocks," to which we have only briefly referred is a disadvantage of the foregoing systems, inasmuch as every additional elaboration not only adds to the prime cost but, in addition, increases the liability to breakdown, the necessity for careful and more frequent inspection, and the cost of upkeep generally. These and other developments in the handling of tramcar and train traffic led the General Electric Company, of Schenectady, to devise a method of control, technically denominated the P. C. control, in which the motor-circuit contactors are operated mechanically by cams carried upon a shaft rotated by electrically controlled pneumatic cylinders.

Fig. 1,869. A Cam-operated Contactor.

One of the contactor units of the P. C. controller is shown in Fig. 1,869 with the arc chute removed. This unit takes the place of the much more elaborate unit already illustrated in Fig. 1,850. Except for a powerful blow-out magnet it is purely mechanical. The circuit gap on the right is closed by the lower jaw being forced upward by a cam rotating on a shaft at right angles to the plane of the linkages and bearing against the roller R. The upper movement compresses the spring S, which opens the contacts smartly as soon as the cam has passed. The upper contact c_1 is fixed, and the lower contact c_2, which is forced upward by the cam, is carried by a short lever pivoted at p. This secures, as c_2 is pressed home, the rubbing contact which is so desirable.

A rear view of the complete apparatus with the covers removed is given in Fig. 1870. The right-hand half is the section containing 10 contactors of the type shown in Fig. 1869, with the cam shaft below them running the whole length of the section. This cam shaft is rotated by a pinion which is actuated by a rack moved backwards or forwards by two pneumatic cylinders, the back of one of which can be seen at C. The pressure air, if admitted to one cylinder, known as the "on" cylinder, moves the rack so as to rotate the shaft in what may be called the positive direction in which the circuits are closed in the usual sequence for accelerating, whilst pressure air admitted to the other, or "off" cylinder, acts in the reverse direction. The admission of air to each cylinder is governed by a magnetically controlled valve attached to it. The "on" cylinder valve admits compressed air to the cylinder when its magnet is energised, whereas the "off" cylinder valve releases the compressed air from the cylinder when its control magnet receives current. Thus, if both control magnets are without current, the "on" cylinder is powerless but the "off" cylinder holds the rack hard over in the "off" position; the reverse is the case when both magnets are energised. In actual working both magnets being out of action and the rack being held in the "off" position, the "on" magnet is first energised, and air is admitted to the "on" cylinder. This equalises the pressure in the two cylinders, and the shaft is then rotated by reducing the pressure in the "off" cylinder. The reduction is governed by the "off" magnet valve, and thus the rotation of the shaft from the first series position to the last parallel position is controlled by a single magnet.

The currents energising the magnets are controlled by a cylinder con-

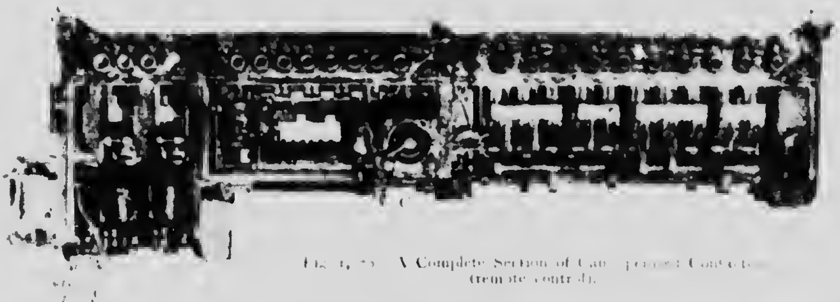


Fig. 1,870. A Complete Section of Cam-operated Contactors (remote control).

troller on the cam shaft to the left of the air cylinders, and this cylinder carries contacts also for the reverser and the main circuit breaker which are still farther to the left. Considerations of space compel us to omit details of these, but it may be remarked that the controller cylinder takes the place of the interlocks of the earlier apparatus, which is thus much simplified. There is also an overload relay operated by the line current and actuating an armature which acts upon contacts in the control circuits. The contactors on which heavy currents are broken are provided with an auxiliary arc chute, easily renewable, which takes the final break.

A diagram of the power circuits for a four-motor 600-volt equipment is given in Fig. 1,871, and the sequence in which each of the 10 contactors, which can be seen in Fig. 1,870, is operated is given in the table in Fig. 1,872. There are 9 operating and one transition step. The reader is advised to work through and ascertain the electrical position on each step.

The control current required on a 600-volt circuit is only 0·3 ampere per car, and as only part of the small amount of energy represented is required to operate the magnet valves, it is possible to supply this energy from a battery carried on the car if it be more convenient to do so.

II(B.). HIGH-VOLTAGE CONTROL

Beyond more effective insulation of all the parts of the contactors, switches, etc., subjected to the high voltage, and the provision of more powerful magnetic blow-outs and longer creepage distances, the design of high-voltage c.c. controlling apparatus, as made by the leading manufacturers, has followed the lines of the similar apparatus used for lower voltages, the general design being little changed. In some cases, however, a double break is made at the contactor by the use of a bridging piece, open-circuiting two fixed contacts instead of one of these contacts being movable. We do not propose, however, to give further details of the controlling apparatus, but one or two matters of interest may be mentioned.

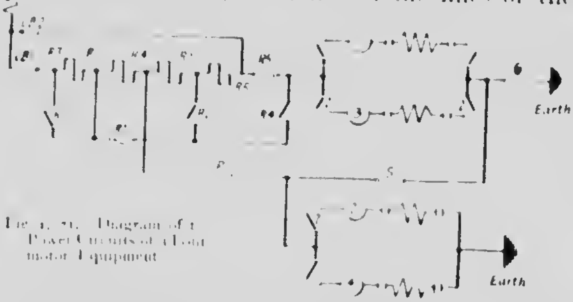


Fig. 1,871. Diagram of Power Circuits of a Four-motor Equipment

It will be remembered that, as explained elsewhere, one of the methods of utilising a high voltage on the distributing conductor without setting up conditions too severe to be handled on the commutator of a c.c. motor, is to connect two such motors permanently in series, and to treat each pair as a single unit, thereby halving the maximum voltage placed across the terminals of any one motor. Thus, two 1,200-volt motors connected in this way would allow a supply voltage of 2,400 volts or thereabouts on the trolley wire or the third rail.

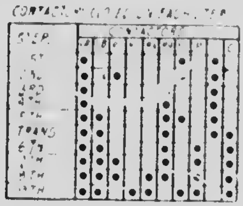


Fig. 1,872. Sequence of Operations for Fig. 1,871

With two pairs of motors so connected the ordinary series-parallel controller, with improved insulation, or any of its modifications, can be employed, but it is worthy of note that in the most modern systems a much greater number of resistance steps is considered necessary for heavy railway working than is used in ordinary tramcar working. To illustrate this point, Fig. 1,873 shows in skeleton form the motor circuits and the electrical positions of the various contactors used on the 3,000-volt equipment of the locomotives of the Chicago, Milwaukee and St. Paul railway. The motors employed are the single-reduction 1,500-volt motors described at pages 1605 *et seq.*

It will be noticed that the controlling resistance is in no fewer than sixteen sections, so that for series running the controller has sixteen resistance steps and one full series running step. The sequences of the closing of the contactors for all the control steps up to full parallel are tabulated in Fig. 1,874, which shows that following the 17 series steps there are, in order, 7 "switch transfer" steps, 2 transition steps, 11 steps for parallel running under resistance control, and finally the step for full parallel running. For the highest speeds there is one additional step in which, with the motors in full parallel, contactors 1 and 26 are closed, thereby shunting the field coils and weakening the field flux. There are thus 32 running positions leading to smooth acceleration and allowing the locomotive to work close up to the slipping point of the wheels, which is a great advantage where the gradients are heavy, as in the Rocky Mountains. The drawbar pull, by careful driving, can be made practically constant and continuous.

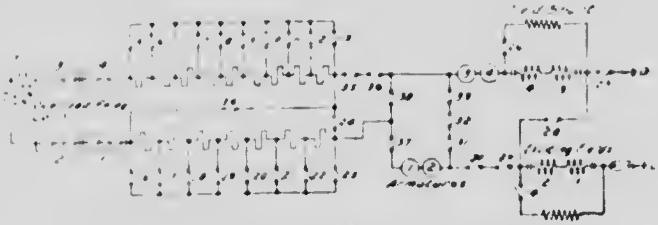


Fig. [illegible].—[illegible] Main Circuits [illegible] volt [illegible] Equipment.

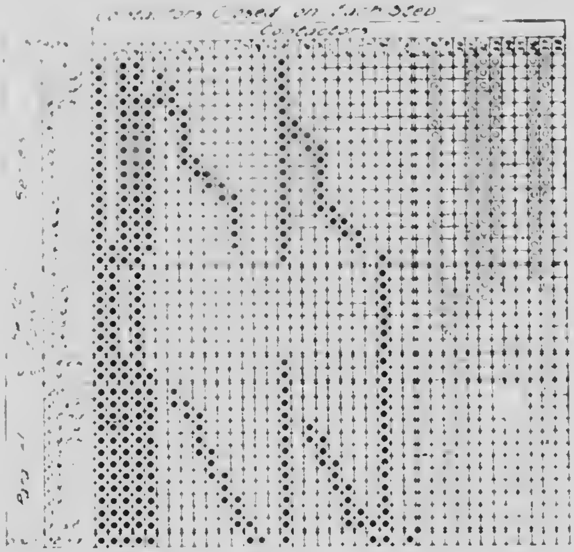


Fig. 1,874.—Sequence of the Closing and Opening of the Contactors (Fig. [illegible]).

The high insulation of the various parts of the apparatus will be realised by an inspection of Fig. 1,875, which shows the mounting of one of the resistance frames or rheostats in which 3,000-volt insulators are used as supports. For comparison on this point reference may be made to Fig. 758, page 714, which shows a resistance frame for use in the low voltage circuits of the rotor of an induction motor. It should be noticed that the field coils are placed on the "earth" side of all the armature circuits, and therefore need not be so heavily insulated, whether the armatures are in series or in parallel.

Reversing is accomplished by reversing the field, instead of the armature connections, as is usual in lower voltage working, and therefore the reversing switches need not be heavily insulated. On the other hand the overhead relays, for tripping the main switches in the event of a heavy overload, are necessarily at the high-voltage end of the circuits and must be well insulated.

Fig. 1,875.—A Highly Insulated Resistance Section.

Auxiliary Circuits.—An interesting and consequential development occurs in the special arrangements for supplying current to the auxiliary circuits for lighting, air compressing, and heating. For the earlier high-voltage equipment, up to 1,200 or 1,500 volts, a motor-generator set was usually installed to supply current to such circuits, and though these sets at first gave trouble they have been improved, and now give excellent results.

When the line voltage rose to 5,000, it seemed desirable to adopt some other method, and one successful solution is shown diagrammatically in Fig. 1,876. Neglecting, for the moment, the motor circuits, it will be noticed that between the contactor C, through which the currents from all the motors flow in their passage to the earth E, and F there are interposed two secondary batteries and the compressor motor, all in parallel. The diagram is for a 5,000-volt supply, and the normal voltage of the batteries is 150, or 3 per cent. of the line voltage. As the average current taken by the auxiliaries is about 80 per cent. of the average current taken by the large motors, it follows that the auxiliaries absorb less than 3 per cent. of the energy supplied to the train. The battery is, of course, under charge when the train is running and taking power from the line, and whilst the train is standing it discharges supplying power to the auxiliary circuits including the compressor.

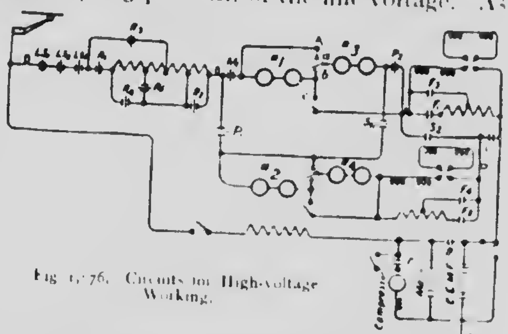


Fig. 1,876. Circuits for High-voltage Working.

Double-voltage Working.—The diagram in Fig. 1,876, to which the switching tables in Fig. 1,877 refer, is interesting as giving an outline of the method of control adopted when at some part of its route the car or train receives energy at 5,000 volts, and at another part, say in passing through a town, the supply circuits are at 600 volts only. This case occurs on a line operated by the Michigan United Traction Company, from which the above named figures are taken.

In the diagram four pairs of armatures are shown, each pair being connected in series; each armature can operate with 1,200 volts on its commutator, and therefore two pairs can, with the field resistance and the auxiliary battery, take charge of the full line voltage. An examination of the left hand switching table will show that for the first six steps of the controller the whole four pairs of armatures are in series, and that the usual rheostatic control is operated with the resistances R_1 to R_5. For working out the details it should be explained that the throw over switches vertically below the letter A (Fig. 1,870) have, for high voltage working, the contacts *b* closed, and *a* and *c* open. Also it may be further explained that the contactors indicated by three parallel lines are of the double break type mentioned above, whilst those indicated by two parallel lines have only a single break. The former take charge of high-voltage breaks, whilst the latter, being electrically near E, have only to handle breaks of much lower voltage. In the transition stage, by closing P_2 before S_1 and S_2 are opened, the lower line of motors is momentarily short-circuited, but "Step 7" is quickly reached, and the two groups of four armatures each are then in parallel through the controlling resistances.

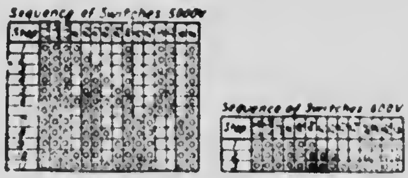


Fig. 1,87[illegible].—High and Low voltage working with the same Motors.

Not to dwell longer on these interesting points, the change over to low voltage working is made with the current "off," by throwing over the line of switches vertically under A, consisting of two two way and two single way switches, all coupled together and operated by one lever. The result is to close the gaps *a* and *c*, and to open the gaps *b*. If the reader will now refer to the right hand switching table he will find that the four pairs of armatures are thus placed in parallel, with all the controlling resistances R_1 to R_5 cut out. The controller used has only three steps, and the control is accomplished by shunting parts of the field windings, a most interesting method, to which allusion has been made several times. It must be remembered that at full field and speed each pair of armatures takes 2,400 volts, and therefore it may be assumed that 600 volts may momentarily be switched on to the paralleled 2,400-volt sets even when standing still, and also that at low speeds these sets will develop sufficient back E.M.F. to run well on 600 volts. This is the position on "Step 1." On "Step 2" the closing of contactors F_1 and F_2 shunts the field coils of each group, a process which is carried farther on "Step 3." With the weakened fields higher speeds will be required to reach the 600-volt working level, and thus the required control is obtained. Moreover, the speeds required in the town are probably much lower than in the open country, where a voltage of 5,000 is available.

It may be observed that this method of control would be too costly if 600 volts only had to be used, and that it can only be by careful design and the use of interpoles that it is possible to use it successfully under the conditions obtaining in this case. The results are reported to be "very satisfactory."

(iii.) OTHER WORKING DETAILS

C.C. Control Economies. The methods so far described for the starting and control of series wound c.c. traction motors, either singly or in pairs, by using the series parallel principle, depend largely upon the introduction of resistances into the circuit for reducing the voltage on the terminals of any motor when it is standing still or running below ordinary economical speeds. As already pointed out (see page 1633), some relief is obtained for low running speeds by placing two motors in series, for then each motor only receives and utilises one-half of the voltage supplied. Even in this case, however, as an inspection of the diagrams given will show, resistances have to be employed in the case of modern motors to moderate the current when starting up, and also when running dead slow. The currents are heavy, and whilst the resistances are in use these resistances absorb a very appreciable, and sometimes a large, fraction of the total energy which is being supplied. Where therefore, as in tramway working, or on suburban railway lines, the stopping places are close together, the fraction of the total energy which thus disappears may add materially to the working expenses. Moreover, the resistances which carry these large currents are expensive, and increase the capital account, whilst their supervision and upkeep add to the running charges. Their use is a weak point in c.c. electric traction for the cases mentioned. For long-distance express traffic the conditions are obviously different.

Non rheostatic Control. These considerations have led to the further development of the series-parallel system which is possible when, as on the Pittsburgh tramways and on certain suburban railways, four motors are available on which to ring the changes. By placing the four motors in series each only receives one-quarter of the line voltage, and it is found in practice that when so arranged a single additional resistance placed in series is sufficient for starting from rest, and that an economical running position at quite a low speed is obtained when this starting resistance is cut out and the four motors placed across the mains in simple series.

Other possible and economical running positions are obviously (ii.) with the motors two in series and two parallel, and (iii.) with the motors all in parallel. These positions and the transition non-running steps by which they are successively reached are shown diagrammatically in Fig. 1,878. Each motor with its series field magnet resistance is indicated by numbered circle, and eight controller steps are shown. Of these No. 1 is the starting step with the motors and the starting resistance R_1 all in series; as soon as the car is well under weigh the controller is moved to No. 2, which is the first running notch, with the motors all in series without any extra resistance added. In practice it is found that the motormen frequently use this notch when following behind slow moving wagons, or when running through congested traffic. No. 3 is a transition stage in which the junction between motors 2 and 3 is temporarily earthed, and the earth taken off motor 4. Only quite a short interval is spent on this step, the handle being quickly turned to notch No. 4, which is a running notch with the motors arranged in two pairs in parallel again but no extraneous resistance in circuit. This corresponds to the full series running notch of an ordinary two motor controller, in which all the controlling resistances are cut out and each motor receives half voltage.

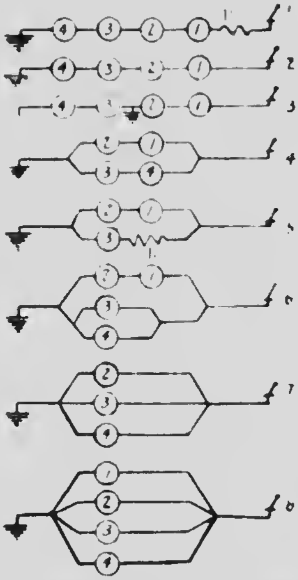


Fig. 1,878.—Non-rheostatic Control Steps.

Three transition stages are interposed between this notch and the final running notch No. 8. In the first (No. 5) motor 4 is replaced by a dead resistance, R_2; in the second (No. 6), an obviously undesirable arrangement, motors 3 and 4 are paralleled and placed in parallel with motors 1 and 2 which are still in series. In the third transition step (No. 7) motor 1 is out of circuit altogether, the running being taken up by motors 2, 3 and 4, which are in parallel. These three steps should be passed through rapidly up to No. 8, in which the four motors are in full parallel with all external resistance short circuited.

In carrying out these changes only nine contactors are found to be necessary, these being placed electrically in the positions shown in Fig. 1,879. On the Pittsburgh cars these contactors are assembled in two group cases, which are small enough to be mounted under the low floor of the car shown in Fig. 1,830. The sequence in which the contactors are closed is given in the table in Fig. 1,880, which should be compared with the foregoing description. Resistances are only used on the transition points 1 and 5, and tests made over a long period show that the energy consumption is from 8 to 15 per cent. less than with a standard series parallel rheostatic controller used on cars of the same weight running on a similar service.

A greater number of economical running speeds could be obtained with this system by using the principle of field control referred to elsewhere (*see* pages 1606 and 1646 and Fig. 1,917, *infra*). This would make the system less simple, but the added complications would, it is asserted, give a speed flexibility equal to that of the steam locomotive.

Whilst the controller handle is being thrown into the "off" position it is necessary to provide closed circuits of low resistance to discharge the energy stored in the magnetic fields of the motors. This is accomplished by special arrangements of interlocks not shown in Fig. 1,879, which hold the motors in parallel groups sufficiently long for the necessary discharge.

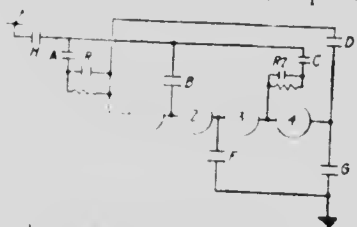


Fig. [illegible].—Circuits and Contactors for Non-rheostatic Control.

Safety Devices.—In electric traction the safety devices which are common to most electric utilisation systems are, of course, employed where and as they are found necessary. These are fully described elsewhere in the book, and comprise *fuses, lightning arresters, automatic circuit-breakers, etc.* Particular designs may be and are modified for traction service, chiefly in the direction of meeting the more severe conditions, but the same principles are involved, and the modifications need not be specifically described here.

There are, however, special safety devices peculiar to traction work which are of interest, and some of these have already been referred to in the previous pages. They are mainly directed towards protecting the employees and the public from accidental contact with exposed conductors carrying currents at a voltage dangerous to life. Amongst these may be mentioned the *guards* on the third rails (*see* pages 1529, 1535, and elsewhere), the precautions (*see* page 1567) taken to protect the driver on high-voltage systems, etc.

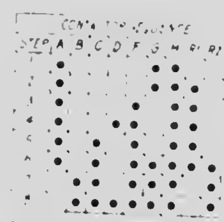


Fig. [illegible].—Contactor Sequence for Non-rheostatic Control.

There is, however, one contingency not guarded against in any of these devices, and which though not confined to traction service, is in such service more liable, when it does take place, to lead to serious consequences. Whether it be a light tram-car, a crowded passenger train, or a heavy freight train hauling more than 1,000 tons, it is, when running, under the control of a single human being who, like all of us, is liable to sudden loss of consciousness. Suppose a driver should lose consciousness, with the controller handle on the full-speed notch, and with no one at hand to step into his place. What will happen? The power is being picked up as the train travels, and everything is set for a full-speed run to destruction. The contingency though remote *must* be guarded against.

One obvious solution is always to have another competent man with the driver and ready to take his place, especially on trains travelling at high speeds and at night time. This solution, however, requires that the staff of trained drivers shall be approximately doubled in number, and has the further disadvantage that the extra man has to spend most of his time in enforced idleness, and that is not naturally good for him. What is clearly wanted is some automatic device which shall operate effectively as soon as the controller handle is released from the conscious control of the driver.

For instance, if the turning of the handle from the "off" position coiled up a sufficiently powerful spring, the handle when released would fly back to the "off" position, where it could be pulled up by a stop. The working of an ordinary heavy current tramway controller fitted with such a device would, however, soon fatigue even a robust driver. But the idea can be utilised in a master controller for automatic control in railway working which only handles comparatively small control currents. In such controllers the handle is not removable, and the cylinder rotates against the torque of a restoring spring which immediately returns it to the "off" position if the handle be released.

The device known as the "*dead-man's handle*" was introduced more than a decade ago in the form of a spring knob on the top of the main handle of the controller. It can be seen on the handle of the B.T.H. controller in Fig. 1856. This knob had to be pressed down before the controller could be operated, and had to be held down whilst the controller was in use. If the knob were released, even for a moment, a mechanical device was brought into play, opening a switch in the controller which cut off the main power current, simultaneously putting on the Westinghouse air brake. Thus, if anything caused the driver to become incapacitated whilst the train was in motion, it was instantly pulled up.

The general method of operation of such a device is to arrange that the depression of the knob shall, by a suitable mechanical contrivance, close the circuit between two contacts, discs, or fingers placed in series in the main control circuit. Until these are closed control currents cannot be obtained, and when they are disconnected, by the knob being released, all control circuits are broken and the power shut off from the train. The same circuit can also be arranged so that, when broken, the air-brake is brought into operation, sand is poured on the rails, and the doors unlocked if, as in some modern systems, they have to be electrically locked before the car can start.

Position of Regulating Apparatus. The question of the positions in which the various pieces of apparatus required for starting, speed regulation, etc., are to be carried on the motor coach or train, is one which requires careful consideration. It is obvious that the master controllers and all apparatus which has to be operated directly by the driver of the motor-coach or tram must be placed within his reach in a compartment or "cab," from which he has a clear view of the track in front of the train and all the signals which he is approaching, and by which he has to be guided. Illustrations of driver's cabs have already been given in Figs. 1,832 and 1,864 *ante*, and one or two further examples will be given presently. Much of the apparatus controlled from the cab, apart from the motors which must necessarily be close to the driving axles, is so heavy and bulky that it could only be carried in the driver's cab by considerably increasing the size of the cab, and thus adding to the length of the

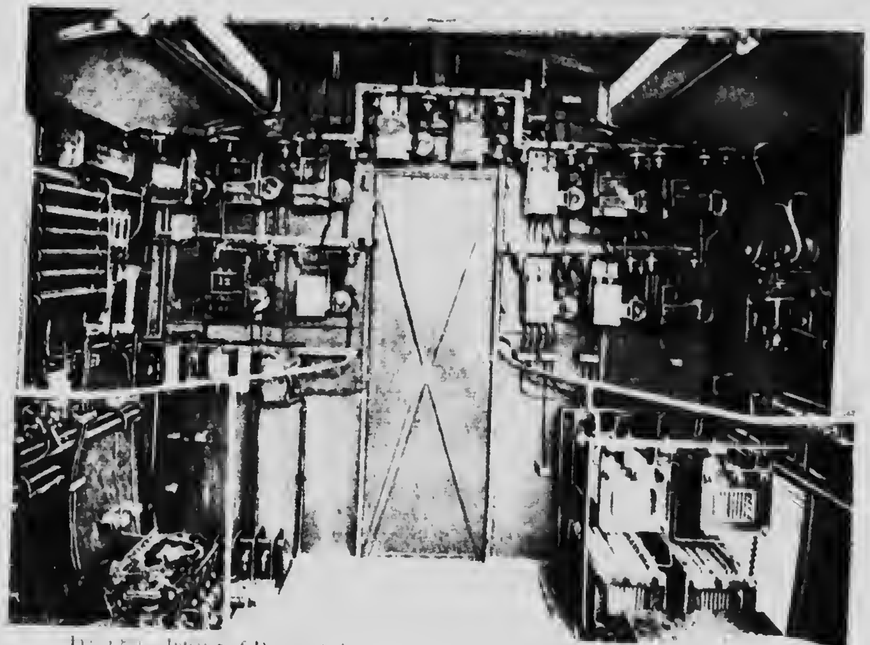


Fig. [illegible].—Interior of Driver's Cab on the Great Northern and City Railway (London, [illegible]).

train. The apparatus referred to consists of the heavy current resistances, resistance rheostats, contactors, reversers, etc., which need not be in the cab, but must be so placed as to be readily accessible for inspection and repair.

In some of the illustrations already given, Figs. 1,862 and 1,868, these necessary accessories have been shown in position on the under surface of the motor coach. In certain respects this is not a very accessible position except when the coach is over a pit specially constructed for inspectional and other purposes. The most accessible parts (e.g. close to the outer framework) are, however, selected so as to minimise the inconvenience. The position has, on the other hand, the great advantage that the accessories do not occupy valuable space which might be used for other purposes.

The advantages of easy inspection and repair have, however, in some cases been considered sufficient to justify enlarging the cab so as to enable the more important parts of this apparatus to be placed in a more accessible position. One or two examples of this solution of the problem should be interesting.

The rear part of the interior of the driver's compartment on one of the 1906 motor coaches of the Great Northern and City Railway is shown in Fig. 1,881. This view shows how all the contactors, reversers, and rheostats are brought together in a position where they are always open to inspection and are secure from dirt and damage. The floor space available is 7 ft. by 9 ft., and the panels of the partition behind the apparatus at the back of the compartment are removable, so that this gear is accessible on all sides. The conducting connections are made by bare copper rods carried by earthenware cleats. The position of the driver or motorman is in front of the apparatus shown in Fig. 1,881, which lies behind him when he is handling the train.

Fig. 1,882.—A Train Unit on a London Suburban Railway [illegible].

Another example, taken from the columns of *The Electrician*, is given in Figs. 1,883 to 1,886, which illustrate the control apparatus adopted by the London and South Western Railway in the electrification of parts of its metropolitan suburban system, the first portion of which was completed in 1915. The system is a continuous-current system at 600 volts, with third and fourth rails for the supply of power to the moving trains.

A complete unit of the train equipment is shown in Fig. 1,882. The unit consists of two motor-coaches with a trailer coach close coupled between them. There is a driving cab at each end of the unit, and two units can be coupled and run together from either end when the traffic is heavy, Each unit weighs 94 tons unloaded, carries 190 passengers, weighing, say 12 to 13 tons, and is driven by four 275-H.P. motors, the motor bogies being directly beneath the driver's cab at each end.

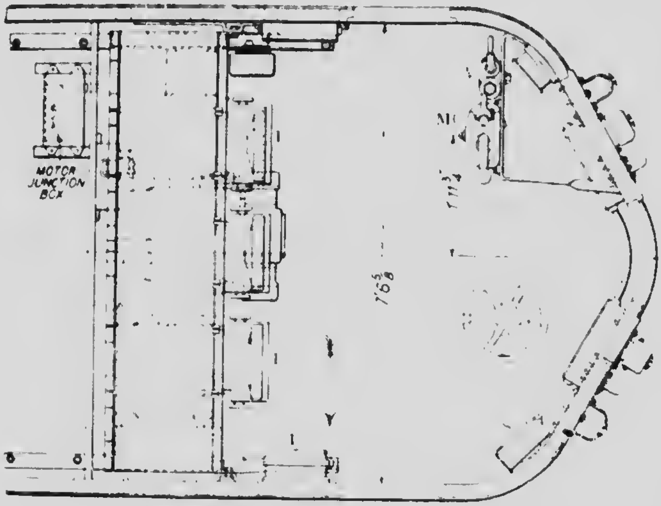


Fig. 1,883.—Plan of Driver's Cab in London Train Unit

A plan of one of the driver's cabs is given in Fig. 1,883, from which and from Fig. 1,882 it will be noted that the end of the coach is rounded off, giving, besides a straight-ahead observation window, two observation windows, one on either side, set at an angle. As the driver stands facing the windows the master controller M C, and the pneumatic brake valve V are within reach on his left, and the handbrake wheel on his right hand. The various other parts of the controlling and operating apparatus are arranged on the walls of the cab on either side of him, the heavier parts being installed behind him in the rear of the compartment.

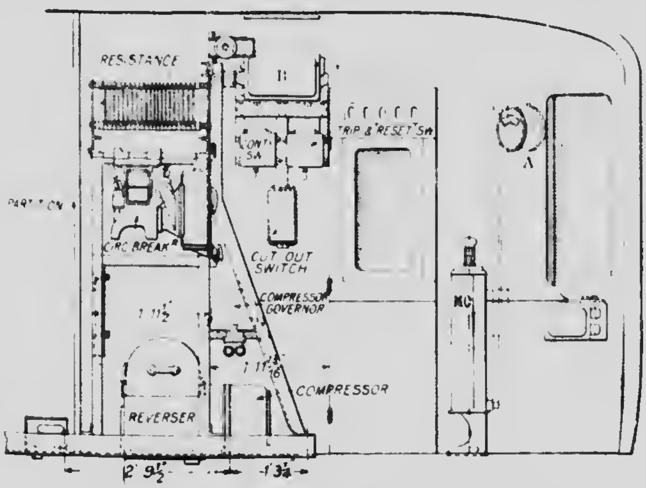


Fig. 1,884.—Apparatus on Left-hand Side of Driver's Cab.

On the left hand vertical side of the cab, shown in Fig. 1,884 there is an indicating ammeter, A at a convenient height for continuous observation of the current, whilst to the left of the doorway are the cut out, tripping, and control switches, arranged immediately beneath the control junction box, B, through which pass the wires from the master controller to the various circuits. Still farther to the left is the main circuit breaker. On the opposite vertical side (Fig. 1,885) the most interesting piece of apparatus is the automatic limit relay, L, which controls, during the accelerating periods, the supply of current to the motors of the particular coach in which it is installed. On the left side of the door is a box, S, containing the switches for the lighting and heating circuits of the unit.

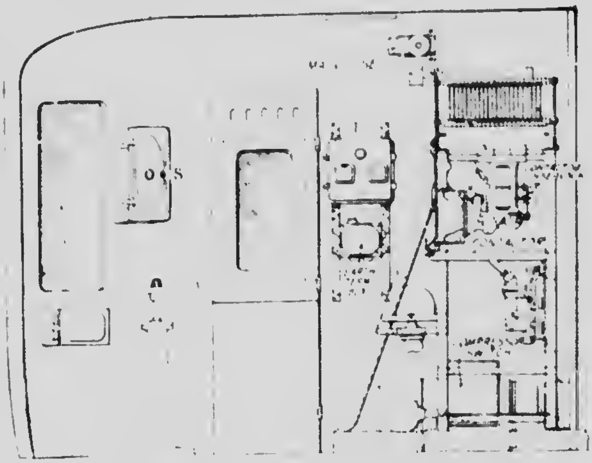


Fig. 1,885. Apparatus at Right-hand Side of Driver's Cab.

The back of the cab is shown in elevation in Fig. 1,886, in which it will be seen that the main fuses, FF, projecting forward (Figs. 1,883 and 1,885) are ranged along the top, and below them are the heavy current resistances, RR. On a lower shelf are the contactors and circuit breakers, whilst still lower are the compressor, for the supply of compressed air for the pneumatic brakes, together with its motor, switches, etc. All this apparatus is conveniently placed so as to be easily inspected and overhauled, and any part of it adjusted should necessity arise.

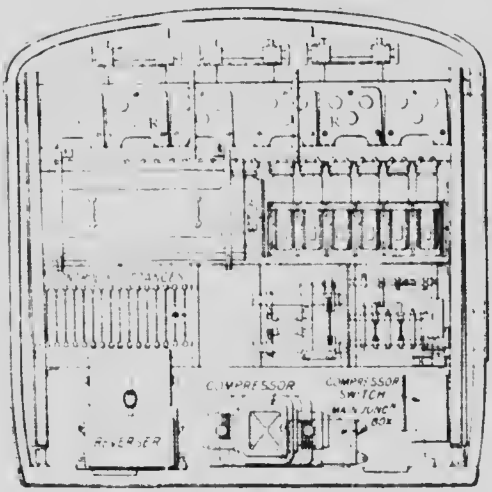


Fig. 1,886. Apparatus at the Back of Driver's Cab.

In operating the master controller all that the driver has to do to start the train is first to move the reversing handle of the controller to the "forward" or "reverse" position, as, until this is done the main handle is locked. He then presses down the "dead man" plunger in the main handle, and moves this handle over to the full "on" position, always maintaining his grip on the plunger. All the limit relays on the train then begin to operate and notch up the motors on the different coaches in accordance with their individual requirements, thus ensuring the equalisation of the load on the various pairs of motors. The supply voltage is 600 volts, but if through any cause this voltage is seriously lowered, the adjustments are such that any two motors in series will come into action with as low a pressure as 350 volts, and the relays will not notch over to the parallel connection if the pressure be below 470 volts, an obvious advantage should the pressure ever be so reduced. Should the driver inadvertently or otherwise release the "dead-man's" plunger, the control current would be cut off, all the contactors would open, and all the brakes be automatically applied. The train would thus be quickly brought to a standstill, and the driver cannot release the brakes, or again set the relays in operation, until he brings the operating handle to the "off" position and makes a fresh start. Although, as mentioned, the driver may move the operating handle to the full "on" position, he may pause on any one of the three other running positions. On the first the motors are in series, with all resistances in; on the second the automatic relays are brought into play, and notch up the contactors until the motors are in full series without resistances. The third position changes the motors from series to parallel, the bridge connections (*see* Fig. 1,819) being used for the transition stage. The fourth or full "on" position brings the automatic relays again into play to cut out again the resistances step by step to the full parallel position.

Car Wiring. The running of the various circuits required either for direct or remote control of the motors and for working the other electric apparatus, including lighting, heating, driving the air compressors for the brakes and other services, is a matter which has to be carefully thought out with the possibility of a serious breakdown as the penalty of carelessness. One has only to look at some of the diagrams given elsewhere (e.g. Figs. 1,837 and 1,863) to gather that the requirements for successful working are complicated. Moreover, in these diagrams many of the subsidiary working and safety devices have been omitted, and the diagrams actually reproduced are far from being the most complicated which appear in actual practice.

The principles involved in these working and safety devices are dealt with, and examples given of typical apparatus, elsewhere in this book, and we therefore do not propose to go into this particular application here. Some idea of the practical solution of the problems involved will be gathered from an inspection of Fig. 1,802, showing the under part of a motor coach fitted with B.T.H. control apparatus. As a more direct example of an important part of the wiring of a motor coach, Fig. 1,887 shows the wiring underneath the floor of one of the motor-coaches running on the South London line of the London, Brighton and South Coast Railway. It will be noticed that proper chases are provided for the single and multiple cables, which have to run any distance along the car, and the main chase runs lengthways down the middle of the car. Accessibility for inspection and repair is, of course, one of the essentials to be borne in mind in planning the scheme of wiring.

Fig. 1,887.—Wiring underneath the Floor of a Motor-coach for Single-phase Working.

III. A.C. POWER CONTROL ON RAILWAYS

In dealing with the power supplied to moving trains in the form of alternate-current power, many of the considerations which have led to the use of distributed motors in the corresponding continuous-current case still hold. As a matter of fact, however, much greater use has been made of separate locomotives in dealing with alternate-current energy, a fact which perhaps is due partly to accidents of development and local requirements, but is also to some extent to be accounted for by the greater flexibility inherent in alternate-current methods generally, and to the much higher voltages which can be safely introduced into and practically handled on the moving vehicles. These and some other general points have already been briefly summarised on page 801 at the beginning of the section on "Monophase Traction Motors."

The outstanding advantage of A.C. working as compared with C.C. working is that for starting purposes the full running voltage can be lowered by more economical methods than by absorbing some of the temporarily redundant voltage by passing more or less heavy currents through resistances, which leads to a wasteful expenditure of energy in the heating of the regulating resistances. In A.C. working a variable voltage for starting or running at a reduced speed or for other purposes can be obtained by methods which have been fully described and criticised elsewhere, such as (i.) by tappings from the secondary windings of a transformer, or by tappings from the windings of an auto-transformer (*see* page 721) and (iii.) by an induction regulator (*see* pages 1298 *et seq.*).

All types of A.C. motors are not available for traction work without some special modification, for the outstanding feature of such work is that the motors must be able to start under full load. The method of control to be utilised in any given case is governed primarily by the conditions for starting the particular type of A.C. motor used. The conditions and the general methods of starting have been dealt with in the chapter on A.C. motors in connection with the consideration of the theory and practical methods of construction of each type of motor described. Thus the methods of starting a polyphase induction motor have been described on pages 717 to 739 with some of the actual switchgear employed for stationary motors, and the chief methods for increasing the starting torque have been discussed. Polyphase commutator motors of various kinds have been dealt with on pages 775 to 788, whilst monophase commutator traction motors will be found described on pages 800 *et seq.*, and the starting and control of one well-known type is given in detail on pages 816 to 818.

Single-phase Working. The reasons which have led to the widespread adoption of the series commutator motor for A.C. single-phase traction have been given (*see* pages 810 *et seq.*) in the chapter describing these motors, where also the difficulties in satisfying the conditions and the methods by which they are overcome are described. We are here concerned chiefly with the control of the power supplied to the motors, which, in order to explain more fully the difficulties referred to, and their solutions, has also been to some extent described in the same section.

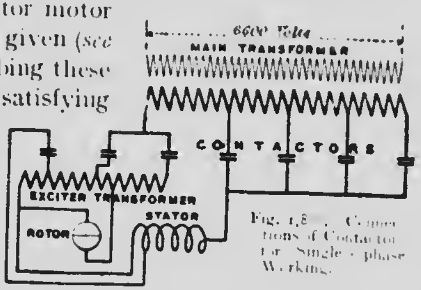


Fig. 1,888.—Connections of Contactors for Single-phase Working.

In this connection reference has been made to the method of controlling the Winter-Eichberg motors used on the London, Brighton and South Coast Railway, the electrification of which has been more fully referred to in the last two chapters. For convenience of reference we reproduce (Fig. 1,888) the diagram of the connections of the contactors previously given in Fig. 845. The supply voltage, as noted elsewhere, is 6,600 volts at 25 ~, on the overhead catenary suspended conductor, from which current is collected by the bow collectors seen in Fig. 1,711. From the bow-collector a high-voltage current is led into the special high-voltage chamber on the motor coach shown in Fig. 1,889, which is of course, in accessible to ordinary attendants. In this chamber there are the usual high-voltage switches, circuit breakers, fuses, etc., described elsewhere, and the main transformer which, as shown in Fig. 1,888, steps down the 6,000 volts to a maximum of 750 volts for use in the motor. There is also a small transformer with its primary in parallel with the main transformer for supplying current at a lower voltage for working the contactors on the control circuits. One end of the secondary of the main transformer shown in Fig. 1,888 has four taps, from which currents at 450, 580, 640, and 750 volts respectively can be drawn through the corresponding contactors. As already explained, there are for each coach four motors in two pairs, one pair on each bogie, the motors on each pair being permanently connected in parallel. Only a single motor is shown diagrammatically in Fig. 1,888. The other pole of the secondary of the main transformer supplies current to an auto-transformer, from which the current for the armatures or "rotors" of the motors are taken. Part of the windings of this transformer are in parallel with the field magnet or "stator" windings of the motors.

Fig. 1,889.—High-voltage Chamber on Motor Coach (L. B. & S. C. Ry.)

The motorman's cab is shown in Fig. 1,890, where can be seen the small controller by which the seven contactors of Fig. 1,888 are worked. Only small low voltage currents for the controller circuits and currents from instrument transformers are introduced into the cab. The controller is of the ordinary cylindric type, and at the motorman's left hand there are the handles for the ordinary and emergency air brakes. A hand-brake can also be seen in the foreground.

As another example of the control of high-voltage single phase power, we give in Fig. 1,891 a view of the one of controllers of the Lötschberg locomotive, which will be found described on pages 1619 to 1621. It has there been explained how the supply current is brought to the primary of the step-down transformer, of which there is one for each of the sixteen pole motors, and that the secondary of the transformer has no fewer than twelve tappings, which are carried to a controller mounted on top of the transformer. The controllers are of the cylindric or drum type, the axle being horizontal. The movable contacts are formed of massive segments, which are carried on spokes projecting from hubs on the axle, and the fixed fingers, which can be seen arranged along the front bar, are massive and well laminated. The contact fingers are directly connected to the transformer tappings. The secondary voltage has a maximum value of 500 volts, so that difficulties of insulation are confined to the primary circuit of the transformer.

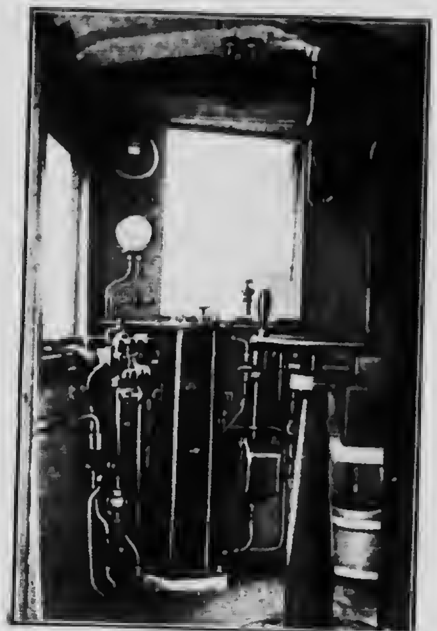
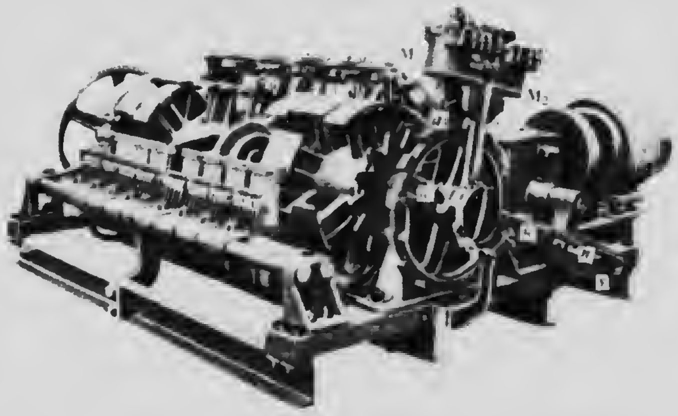


Fig. 1,892.—Motorman's Cab, South London Line (L.B. & S.C. Rly.)

The controller has three chief parts, namely a main drum, an auxiliary drum, and the driving gear. The function of the main drum is to connect two successive tappings of the secondary to an auto-transformer whose middle point is connected direct to the motor through a low-voltage oil switch. The auxiliary drum is used to switch in or out one or other of the auto-transformer circuits. Any interruption of current therefore occurs on this drum, which is provided with a magnetic blow out. The movements of the main drum are made without any interruption of current. The controller can be operated by motor, which is the usual method, or, in cases of emergency, by hand. The motor, which can be seen at the right in Fig. 1,891, is a continuous-current motor driven by a converter set or by a secondary battery, four of which are carried on the car, two at each end. This motor drives, by means of worm gearing, the crank shaft and pin *n* seen at the side. The pin working in the slide *s* oscillates the connecting rod R, and with it the magnets M_1 and M_2 and two pawls, one of which a_1 is worked by the plunger of the magnet M_1 and the other by the plunger of the other magnet. The pawls, when lowered, engage in the notches of the ratchet wheel *w*, one of them by its oscillations moving the wheel clockwise and the other moving it counter-clockwise. Only one electro-magnet can be operated at one time and the corresponding pawl lowered. The electro-magnet is, of course, operated from the driver's cabin. The voltage at the motors can in this way be varied from 90 to 520 volts by [illegible] of 15 volts, thus ensuring smooth starting and acceleration with a minimum of rapid load fluctuation at the generating station when several trains are being worked. For instance, when a train of 370 tons weight is being started on the steepest gradient, 1 in 57, with an acceleration of 5 ins. per second per second, which is quite a slow rate, the locomotive only takes [illegible] per cent. of the current required at full speed with full torque. As the maximum working voltage at the motor is 430 volts, and the power developed is 1,250 H.P., the controller switches as well as the oil switches are designed for a maximum current of 3,000 amperes, the power factor being about 0·95 with all loads at normal speed.

The safety devices in connection with the high-voltage circuit are very complete, and will be found fully described at page 1021.

Single-phase Supply and Three-phase Motors. In the preceding chapter (see page 1025) we have given particulars of a high-powered locomotive used on the Pennsylvania Railway, which, taking single-phase power at 11,000 volts from an overhead conductor, is operated by four three-phase induction motors taking [illegible]



current at 850 volts per phase. As the locomotive is rated at 4,800 H.P. and can develop as much as 7,000 H.P. at starting, the details of the transforming and controlling arrangements for such a case are full of interest.

The general plan of the connections, with the omission of subsidiary apparatus, is given in Fig. 1,862. The pantograph shown in Fig. 1,862 takes from the overhead wire the 11,000 volt current which passes through an oil circuit-breaker to the primary of a single-phase transformer and then to earth through the framework of the locomotive. The secondary of the transformer has numerous tappings, as shown in the diagram (Fig. 1,862), and the method of transformation to three-phase current is that which has already been briefly described in general terms in the chapter on static transformers (see page 950). The phase converter is an induction motor with a squirrel-cage rotor, and with two windings on its stator, 90 electrical degrees apart, as shown more simply in Fig. 1,863 and 1,864 these corresponding to the two windings shown in Fig. 973. One of these the "primary phase," is at full load, connected practically across the full voltage of the secondary, one terminal being connected to the insulated end A (Fig. 1,893) of the secondary, whilst the other terminal for starting and balancing purposes and for different loads may be joined to one of four different points, preventive coils being inserted to limit the current to a safe value when two switches are closed at the same time in transferring from one connecting point to another. One terminal of the second coil, the "secondary phase," is, when on load, connected as shown in Fig. 1,894 and through the necessary preventive coils (Fig. 1,892) to a point P, intermediate between the points A and B of the connections of the primary coil, its other terminal going direct to the train motors. In this coil the reaction of the rotor of the phase-changing induction motor produces a current in quadrature with the primary current, and the T-combination of this current, shown in Fig. 1,894 with the currents in the main transformer secondary, gives the conditions for the well-known Scott transformation from two-phase to three-phase described fully at page 948.

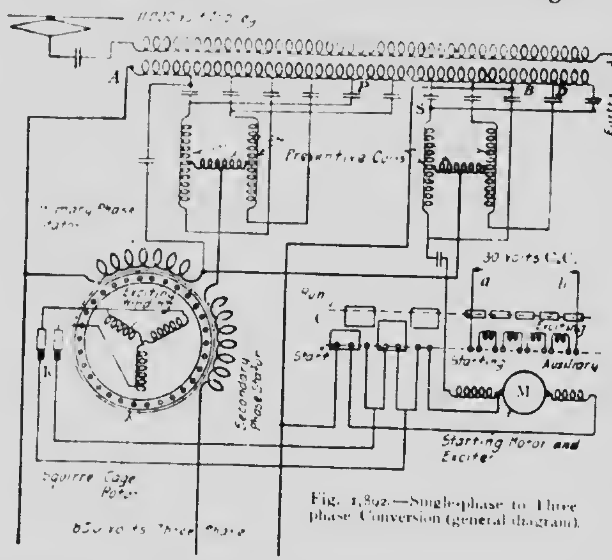


Fig. 1,892.—Single-phase to Three phase Conversion (general diagram).

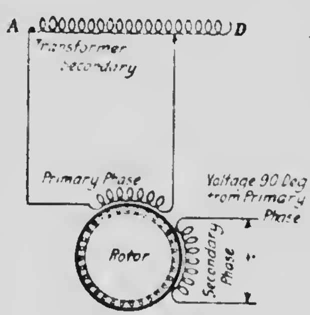


Fig. 1,893.—Positions of Stator Coils.

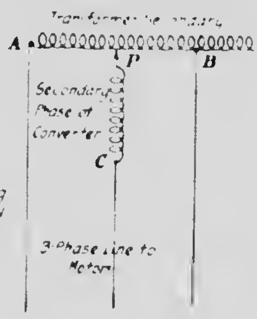


Fig. 1,894.—The Scott or T Connection.

Instead of complicating the principal connections with self-starting devices for the phase-converter, a separate single-phase starting motor, M (Fig. 1,892), is provided. The two-position controller for this machine is shown in outline diagrammatically at C, set for "start." In this position the three-phase winding shown on the rotor of the phase-converter, the function of which we explain below, is short-circuited, and the A.C. starting motor M draws current from the points B and S of the main trasnformer secondary.

The part played by the phase converter in the transformation from single-phase to three-phase currents is obviously fundamental, and, although it is only a squirrel-cage induction motor, good examples of which have already been described, a few details of this particular modification will be of interest. In Figs. 1,805 to 1,808 views are given of the parts of a similar converter, built by the same manufacturers, the Westinghouse Company, of East Pittsburgh, for the Norfolk and Western Railway, on which a similar system was established at a slightly earlier date.

Fig. 1,805.—Stator Frame of Phase Converter

The stator frame and the wound stator are shown in Figs. 1,805 and 1,806 respectively. The frame is in two parts divided by a wide central ventilating duct, a method of construction which was adopted, after careful experiments as both economical and effective. The two halves were built up separately and riveted under pressure between cast-steel end plates, which, on the central end, carried lugs for bolting together as shown. On this frame the stator windings are placed, and electrically divided up as explained above. The whole winding is securely clamped to enable it to stand the vibrations of the locomotive and also the magnetic shocks incident to starting under peak loads and to the bouncing of the trolley wheel.

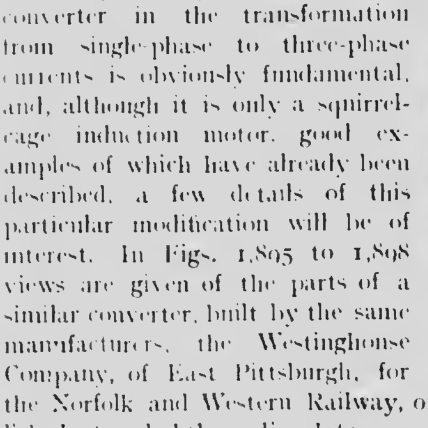


Fig. 1,806.—Wound Stator of Phase Converter.

The rotor is similarly in two halves, one of which is shown in Fig. 1,807, the complete rotor mounted on its shaft being shown in Fig. 1,808. The rotor bars of the squirrel-cage winding were electrically brazed to the short-circuit end rings. The rotor differs from the one built later for the Pennsylvania

Railway in not having the c.c. magnetising winding with slip ring referred to below.

The armature of the series single-phase starting motor is shown in Fig. 1,898, mounted with its commutator on the same shaft as the rotor of the phase converter. On the other end of the shaft there is mounted, but not shown in the figure, a ventilating fan for cooling the converter.

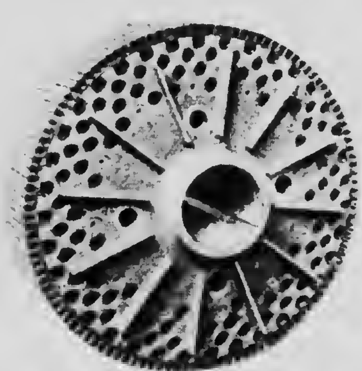


Fig. 1,897. One-half of the Rotor of the Phase Converter.

Returning now to the method of working and the diagrams, when the phase converter has been run up to speed the controller c (Fig. 1,892) is put over on to the "run" position which takes the starting motor M off the main transformer at B and leaves it to be run as a c.c. generator by the converter which can now take power from the main transformer. As a generator the fields of M are separately excited by a 30-volt c.c. current supplied through the terminals *a b* by a small motor generator set not shown in the diagram. The continuous current from M passes through the slip rings R to a three-branched star connected winding on the rotor of the converter, and acts as an excitation current. The object is to improve the power-factor of the phase converter which is much higher with such excitation than when it is excited by the stator currents. It will be remembered that when the rotor of the converter is running at synchronous speed this c.c. excitation revolves mechanically at exactly the same speed as the revolving field, hence the possibility of using this device.

Fig. 1,898. Rotors of Phase Converter and its Starting Motor.

The Master Controller. The three-phase current so obtained is supplied to each of the four motors on the locomotive through five unit switches electro-pneumatically operated by a master controller, the operating levers of which are shown in Fig. 1,899. The lowest of these handles is for "reversing," and operates by interchanging the connections of two of the phases through four of the five switches used in pairs.

The second handle is used to change the normal speed from 10 to 20 miles per hour or *vice versa*. As explained elsewhere, the motors being induction motors have each only one normal running speed, but if used in pairs can be run normally at half speed when connected to the supply circuits in "cascade," and at full speed if connected in parallel. In this case the four motors are used in two such pairs, and when connected in "cascade" the rotor of one motor is connected to the stator of the other, the rotor of which is connected to an adjustable liquid resistance. In parallel, that is at the higher speed, the rotor of each motor is connected to a regulating liquid resistance. The function of the second handle is to make the necessary changes between cascade and parallel operation. It has three positions, namely, a mid way position in addition to the two running positions, this additional position being to allow one pair of motors to be changed over first so as not to lose the mechanical torque entirely by taking off both pairs from the power supply at once.

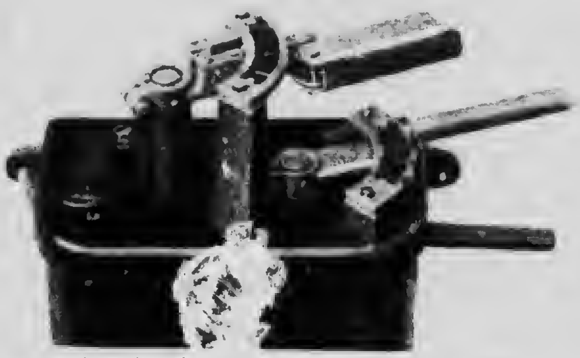


Fig. 1,893.—Master Controller for Three-phase Motors.

The third handle is called the "acceleration" handle, and controls the primary switches in addition to regulating the acceleration. It also has three positions marked "raise," "hold," and "lower" respectively. When moved to "raise," the level of the liquid in each resistance tank is raised by means of a differential air engine; the rise of the liquid lowers the resistance and increases the speed of the motors. On moving to "hold," the level is retained, and at "lower" it is depressed. A current-limiting relay protects against overload; it first acts by arresting the rise of level of the liquid, and then lowers this level if the accelerating current rises beyond a fixed maximum value. The liquid resistances have been very carefully designed to stand the high voltages of operation; the liquid in them is kept in motion by circulating pumps, and a small percentage of it is pumped to cooling towers, whence it is returned to the tanks, the contents of which are thus kept within reasonable temperature limits. These liquid resistances can be seen at the right-hand end of Fig. 1,804. They are placed in the centre of the cab of the locomotive, two on each side of the central cooling tower. Some other details of the control apparatus can also be made out.

Combined A.C. and C.C. Working.—The achievement just described of running successfully, under the severe service conditions of railway work, three-phase motors from a single-phase supply circuit, demonstrates the great flexibility of the supply of A.C. electric power to trains. Perhaps even greater flexibility is shown in a system introduced in 1917 in the Atlantic States of America, in which the same motors are supplied either with alternate or continuous currents as convenience dictates. A brief description of how this is accomplished may appropriately conclude this section.

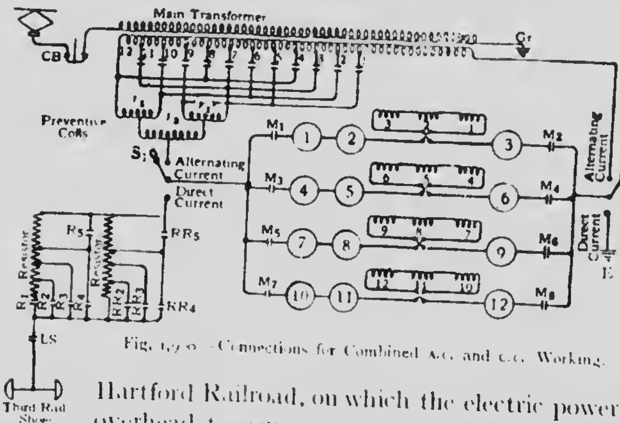


Fig. 1,900.—Connections for Combined A.C. and C.C. Working.

The necessity for such working arises in connection with the passenger service on the New York, New Haven and Hartford Railroad, on which the electric power is supplied from an overhead trolley wire as A.C. power at 11,000 volts. The trains, however, are required to run over the lines of the New York Central and the Pennsylvania Railroad, on which the power is supplied as C.C. power from a third rail.

The motors used are series commutator motors, of which each locomotive carries twelve, which at full power can develop a tractive effort of 47,500 lb. The twelve motors are mechanically geared in pairs to six driving axles. Electrically, however, they are connected in four groups of three each in series, the groups being paralleled as shown in Fig. 1,900, which gives a diagram of the connections and the electrical positions of the controlling contactors, etc. The motors so connected are placed between two switches, S_1 and S_2, which can be thrown over to connect up either the A.C. system shown in the upper part of the diagram or the C.C. system of resistors and contactors shown in the lower part.

In the former case the motors receive energy from the secondary of a transformer which steps down the 11,000 volts of the trolley wire to the working voltage of the motors. The speed control is obtained by using the different taps on the transformer secondary, reactive coils being inserted so that, as usual, when changing from one tap to another by closing the appropriate contactors, the intervening coils of the secondary are not short-circuited, but have reactances bridging them. Thus, as shown in Fig. 1,901, which gives the sequence in which the contactors are closed, the first four controller steps close successively the tap-contactors 1, 2, 3 and 4 without opening any of them. When all these are closed it will be found that none of the secondary coils between 1 and 4 is short-circuited, but that different combinations of the reactances R_1, R_2 and R_3 (Fig. 1,900) are interposed. In closing contactor 5 on the fifth controller position, contactor 1 is opened, for if 1 and 5 are closed at the same time the intervening transformer coils would be short-circuited; contactor 1 is therefore opened before 5 is closed, and similarly for the remaining controller positions, which are all running positions. It should also be noted that not only is the circuit-breaker C B, which has a contactor on each side, kept closed on every step, but also the whole of the motor switches M_1 . . . M_4 are similarly kept closed on every step. The motors are permanently three in series and four parallel. The field coils are also in series in corresponding groups of three, and the direction of rotation and travel is reversed by reversing the field connections with the usual precautions which are not shown in the diagram.

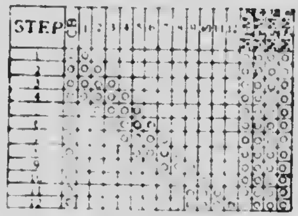


Fig. 1,901.—Sequence of Switches for A.C. Working.

The sequence of the contactor closing for continuous-current working is given in Fig. 1,902, which should be compared with Fig. 1,901. The control is quite simple, for the connections at the motors are the same at every controller notch, and all that is done at each successive notch is to reduce the resistance in series with the whole group of motors, until it is all cut out by being short-circuited; the full-speed running position is, with all controlling contactors, closed. As usual, only the power circuits are shown in Fig. 1,900, the low-voltage circuits for energising the coils of the contactors being omitted.

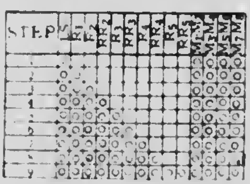


Fig. 1,902.—Sequence of Switches for C.C. Working.

IV.—BRAKING AND REGENERATIVE CONTROL.

It is matter of common knowledge that mechanically driven vehicles, either on railways or on the open highways, could not be safely managed without some provision for more rapidly diminishing the speed, in case of necessity, than is supplied by the friction on a level road and the resistance of the air. Put otherwise, it is a fundamental requirement that some means should be available by which the stored kinetic energy of the mere mass of the vehicle and its load (the $\frac{1}{2} m v^2$ energy), travelling at ordinary or any speed, can be dissipated very rapidly in cases of emergency. If the road be not level, it often occurs that the vehicle can run down grade under gravitational forces only, if no retarding force be available, and therefore even horse-drawn vehicles have to be supplied with some means of applying such a retarding force.

As is also well known, the most usual method of applying the requisite retarding force is to press a movable skid or skids against the rim, hub, or other convenient and suitable part of the rotating wheel or wheels, so as to reduce the rotational velocity of the wheel below that required for the forward movement of the vehicle at the speed at which it is travelling, and thus to bring into play friction between the contact surface of the wheel and the fixed road or rail, by which friction the motion of the vehicle is retarded, and the speed slowed down more or less rapidly. This is the process known as *braking*, and it is widely recognised that for successful braking of this type the wheel should not be so firmly held by the braking block as to cause it to slide or skid on the road or rail, as in that case the friction available for retarding the vehicle is not so great or so effective as when the wheel does not slip or slide on the road.

In ordinary cases the braking block is applied to the wheel by some mechanical contrivance, and much ingenuity has been exercised in the design and invention of convenient methods. We cannot, obviously, enter here into the details of the development of these methods, which will be found in special treatises, but it may not be irrelevant to remind our readers that in the well-known vacuum brake, as applied to railway traffic, the pneumatic action holds the brake-blocks off the rims of the wheels against the thrust of powerful springs. The removal of this holding-off force, either intentionally by the action of the driver, or accidentally by the separation of the vehicles of the train or otherwise, causes the brakes to be immediately applied, and the train or vehicle to be quickly brought to a standstill. It is well to bear this in mind when dealing with electric brakes, with which we are more immediately concerned, and also to remember that however efficient the automatic or electric brakes may be, experience has shown that it is desirable to have available, in case of their insufficiency or failure, some system of *hand-braking* which can be applied quickly by the driver or motorman.

Track Brakes.—It is obviously possible, where electric power is available, to devise electro-magnetic methods of forcing braking blocks against the wheels or of holding them off against springs as in the pneumatic systems, and such methods have been devised and worked out in detail. But with the advent of electrically driven vehicles running on *iron rails*, another type of brake known as a *track brake* has been developed, the fundamental principle of which is to utilise for braking purposes the forces of magnetic attraction, applicable at pleasure, between an electro-magnet carried on the car and the fixed rails on which the car runs. The general method by which this principle is now usually applied, is illustrated in Fig. 1,903, which shows a cross-section through a British Thomson-Houston brake magnet and the rail below it. The section includes a section of the magnetising coil, and the broken line indicates the magnetic circuit, which is completed through the flat part of the road surface of a tram rail of an ordinary pattern.

Fig. 1,903.—Section showing the Magnetic Circuit of a Track Brake and Rail.

An external view of a track brake, taken from a photograph supplied by the British Thomson-Houston Company, is given in Fig. 1,904 from which the details of construction and the arrangements for dismantling the parts for inspection or repair can be made out. It should be noted that the shoes which furnish the friction surfaces can be readily detached and renewed without interfering with any other part of the electro-magnet. The cavity containing the magnetising coil is made watertight, and the leads for the introduction of the current pass through watertight glands. These leads are flexible, and are protected by flexible armouring consisting of an open spiral winding of steel wire.

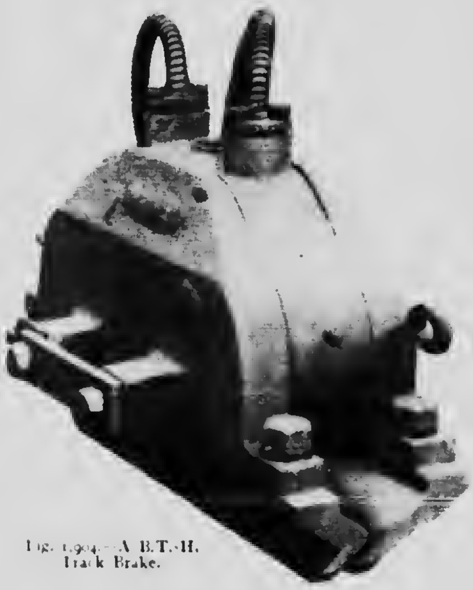


Fig. 1,904.—A B.T.-H. Track Brake.

Electrical connections.—The general theory of the supply of current to these brake magnets has been already fully dealt with at pages 1638 and 1639, where it is explained that, the supply circuit being broken, the current is obtained from the car motors acting as generators, and therefore taking energy from the only source then available, namely, the kinetic energy of the car. A diagram of connections is given in Fig. 1,821. Thus not only is the car retarded by the friction of the track brake, but the motors taking energy from the car set up a backward thrust on the car frame and wheels, for these are now driving the motors instead of the motors driving them. This still further retards the car and tends to bring it to rest.

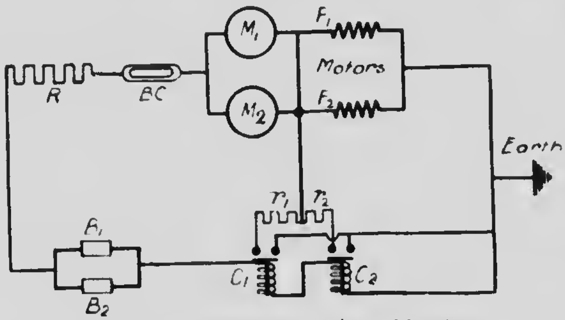


Fig. 1,905.—Connections for a Skid-proof Regulator.

If the magnets only were in circuit, their resistance being small, the motors would be practically short-circuited and very heavy currents would flow. This is obviated in Fig. 1,821 by the introduction of a resistance adjustable from the controller, which has two or more positions for this purpose (*see* Figs. 1,820 and 1,822).

Another method of dealing with the short-circuiting, which has been worked out by the British Westinghouse Company, is to place controlling resistances in parallel with the field coils of the motors, as shown in Fig. 1,905, in which M_1 and M_2 are the motor armatures, and F_1 and F_2 their field coils; B_1 and B_2 are the brake magnets and C_1 and C_2 are solenoids introduced into the magnet circuit between the magnets and earth. A blow-out coil, BC, and a fixed resistance R are also in circuit. The solenoids, C_1 C_2, operate plungers which successively place the auxiliary resistances r_1 and r_2 in parallel with F_1 and F_2, one of the coils—say C_1—being set to operate when the current has risen to, say, 30 amperes, and the other when it rises to, say, 80 amperes. In some variations of the arrangements


Fig. 1,906.—Westinghouse Skid-proof Controlling Attachment.

the coils of c_1 and c_2 are wound as volt coils, and they are placed across the brushes of the motors instead of in series with the brake magnets. In both cases they act automatically when currents from the motors acting as generators become too heavy.

The actual attachment, in which c_1 and c_2 with their plungers and the resistances r_1 and r_2 are mounted, is a substantial piece of apparatus, as will be gathered from an inspection of Fig. 1,906, which shows the attachment with the cover off. One obvious advantage of this attachment is that, being automatic, its action is independent of any careless handling of the controller.

Attachment to Car. In both the diagrams of connections, Figs. 1,821 and 1,905, two brakes are shown because it would obviously be undesirable for mechanical reasons to apply a braking force on one side of the car only. Moreover, for similar reasons, the two brakes should be abreast

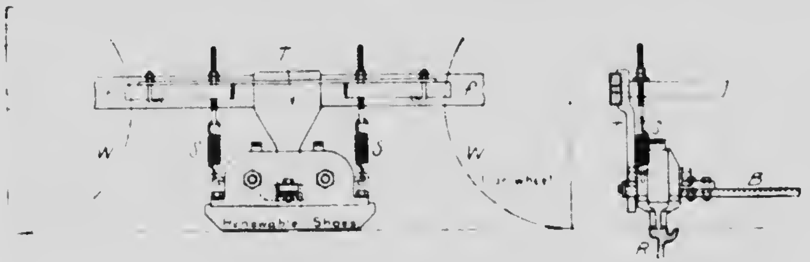


Fig. 1,907. Fig. 1,908.
B.T.-H. Attachment of Track Brake to Car.

of one another, and therefore it is usual to place them opposite one another and couple them together mechanically with a suitable tie-rod, which in the B.T.-H. case consists of $2\frac{1}{2}$-in. by 1-in. channel iron.

The further attachment of the track brakes to the car has to fulfil conditions which are somewhat antagonistic. In the first place the brakes must have sufficient freedom of motion vertically to allow them to ride clear of the rails, with air-gaps not too long when not operating, and to be free to grip the rail when the magnets are energised. In addition, the retarding thrust, consequent on the friction between the magnets and the rails, must be firmly transmitted to the car if it is to be effective. To fulfil these conditions the method of attachment must be carefully designed.

The method adopted by the British Thomson-Houston Company is shown in the outline sketches in Figs. 1,907 and 1,908, of which Fig. 1,907 is a side elevation and Fig. 1,908 an end elevation of the arrangement. Each of the two magnets, which are connected by the crossbar B, is suspended from the truck frame *ff* by spiral springs S S, which hold them just clear of the rail R when not in operation. A thrust bracket, J, firmly bolted to the car frame *ff*, projects downwards, as shown, into the rectangular receptacle in the brake-magnet frame seen in Fig. 1,907, in which it fits loose-tight. In these ways the mechanical conditions are satisfied The adjacent car wheels W W are shown in outline.

The necessary vertical motion of the brake, but more especially the drag of the brake shoes on the rails, can be utilised to operate brake shoes on the rims of the wheels, as indicated in Figs. 1,909 and 1,910, which give two examples of the method adopted for this purpose by the British Westinghouse Company, and fitted to the London County Council tram-

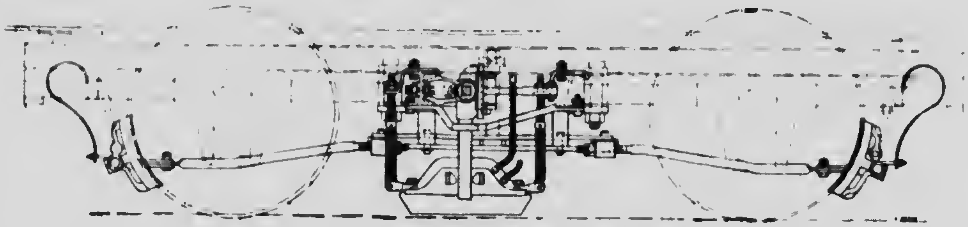


Fig. 1,909. Attachment of the Westinghouse Magnetic Track Brake on a Tramcar Truck.

cars. Both figures are side elevations of the brake shoe with the connecting links and other mechanism in position, Fig. 1,909 showing the magnetic brake fitted to a radial truck, and operating, when the track brake is energised, outside-hung wheel shoes which grip the adjacent wheels fore and aft of the track brake. Fig. 1910 shows the track brake and its fitments modified for application to an equal-wheel bogie truck. For severe gradients a further mechanical attachment is provided by which, through the medium of suitable levers, pull-rods and cranks, the track brakes can be depressed

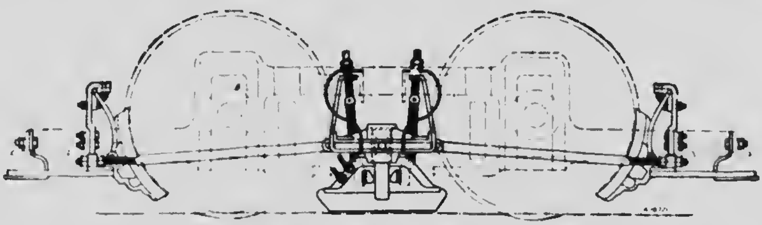


Fig. 1,910.—Westinghouse Attachment of Track Brake to a Bogie Truck.

on to the rails by hand-wheels on the driver's platforms at either end. Thus, if the electrical equipment failed to act, all this braking equipment can be operated by hand from the platforms by the driver or conductor.

Rheostatic Brakes. It is obviously possible to obtain a braking effect by disconnecting the motors from the supply circuits, and connecting their terminals, when running at a good speed, through a suitable resistance or resistances. The motors would then act as generators, and the energy of the current would be converted into low-grade heat in the resistance.

The practical objection to this method in the C.C. case is that the resistances which will absorb the necessary energy, to be of practical use, are costly and heavy, thus adding to the capital charges and increasing the dead weight of the car or locomotive. The same applies to A.C. single-phase working, whilst for three-phase or two-phase working the resistance required to load up the generator motors would be still more costly. In view of the further consideration that these resistances are only used intermittently, this method of braking has not been widely adopted, and is only utilised under exceptional conditions.

Regenerative Working. In traction work the track is seldom dead-level for any length of time, and therefore the train or vehicle is alternately being lifted as it climbs rising gradients and lowered as it runs down a falling gradient. Extra work, as has been shown elsewhere (*see* page 1704), has to be done on the rising gradient as compared with the work required to draw the train on the level, this extra work being stored as potential energy in the raised train. The value of this energy in foot lbs. is easily calculated by multiplying the weight in lbs. of the train or vehicle by the *vertical* lift in feet.

The opposite occurs on a falling gradient, or down grade, the train losing that amount of its potential energy represented by the product of its weight in lbs. by the vertical loss of level. It is a matter of common knowledge that a car or a train will run down a not very steep gradient without receiving any energy from the supply mains, the energy required to overcome the usual resistances and to accelerate the speed of the train being drawn from the stored potential energy of the train when raised to the higher level. In fact, in most cases in practice, the superabundant energy available for these purposes has to be absorbed and dissipated by brakes, and many serious accidents have occurred on down grades because of the failure or the insufficiency of the brakes.

But the supply conductors run alongside the track for the purpose of supplying power to trains ascending the same gradient, and electric motors are reversible machines which, under proper conditions, can be made to act as generators, absorbing mechanical energy and converting it into electrical energy. It is, therefore, an almost obvious deduction from these well-known fundamental principles that, when a train is running down a gradient, its superabundant potential energy, which in any case has to disappear as such, should, instead of being dissipated in wasteful and sometimes costly brakes, be utilised to generate electrical energy which should be *fed back* into the supply conductors for utilisation in other parts of the system—for instance, to drive an ascending train on the rising track on the same gradient. This, if accomplished, is known as *regenerative working*, a descriptive title from other well-known methods used in engineering, metallurgy, etc.

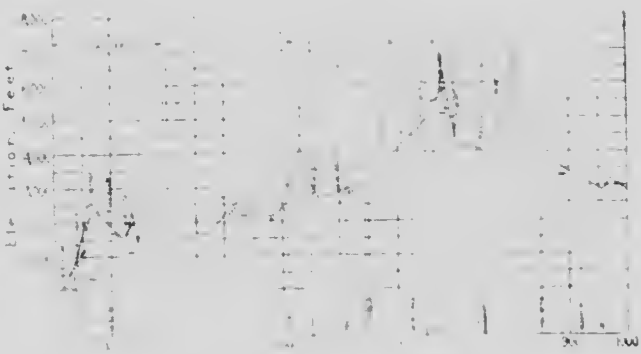
Unfortunately, although the general argument outlined is perfectly sound, the electrical and other conditions to be fulfilled are complicated and difficult; so much is this the case that although the advantages of regenerative working have been clearly recognised from the early days of electric traction, little successful work has been recorded until quite recently in applying it to continuous current systems, which are practically the only ones in common use here. In the first place, it obviously does not lend itself to ordinary tramcar working with its numerous stops and short distances between the stopping points; and our railways are as yet, for the most part, only electrified in the suburban sections, in which the conditions of working resemble the conditions on road and street tramways. In the United States regenerative working is also not much used, but it has been applied on the C.C. locomotives on the Chicago, Milwaukee and St. Paul Railroad, to which references are made later in this section.

In certain kinds of A.C. traction, especially in three-phase systems, the technical conditions are more favourable to regenerative working, and consequently we find that on the Continent, where such systems are fairly common, it has been brought successfully into operation.

C.C. Regenerative Working.—In all regenerative working it is obviously necessary that the generator-acting motor, in order to pump power back on to the supply conductors, must generate an E.M.F. and a P.D. which are in excess of the voltage of the supply mains. The E.M.F. in the armature will be in the right direction to supply a reversed current if the field flux can be maintained unaltered in direction. Unfortunately, however, the standard C.C. traction motor, for reasons which we have developed elsewhere, is a series-wound motor, and therefore, if the connections are unchanged, the reversal of current in the armature will reverse the current in the field circuits, and consequently the field flux which, even if the change could be managed, which it cannot, would reverse the E.M.F.s. The field can only be maintained in its original direction either (1) by a shunt winding in addition to the series winding, or (2) by separate excitation. Either of these methods complicates the controlling arrangements, and the first named has the disadvantage that its use *pro tanto* diminishes, when the machines are running in the ordinary way as motors, those properties of the series motor which make it so well adapted for traction and especially tramway work. However, as regeneration can only be of effective service on long-distance non-stop traffic, this objection is not so serious as would appear at first sight.

Another important objection is that if regenerative working is regularly utilised, the motors will have to be somewhat larger and heavier than the machines used for ordinary working. On lines suitable for regenerative working the motors, as ordinarily worked, only carry current intermittently, for whilst coasting or running down grade with the brakes on the motors are without current, and consequently are cooling down

In one of Mr. R—'s arrangements ... but only the ... coils being reserved for ...



... were divided up ... the different se...

... the ... will ... readers some idea of the difficulties ... overcome, in the early attempts at ... proceed to illustrate some of the ... detail to the most recent locomotives ... Paul Railway designed for regener... sections. That these sections are well ... just laid down will be realized by an ... a profile of 1,000 miles of the railway ... inlet on the coast of the State of ... the mountains where at one point, ...

680 miles from the coast, it reaches an elevation of over 6,000 feet. As is usual in these profiles, the vertical scale is much more open than the horizontal scale, as otherwise either the latter would be unwieldy or the former too minute. In Fig. 1,011 the ratio appears to be about 300 : 1, in other words, one mile plotted vertically is given as much space as 300 miles horizontally. This, of course, exaggerates the steepness of the gradients, but gives a more vivid idea of the variation of level. In this particular profile it will be noted that there are long stretches in which the grading is all in one direction, one of these being over 200 miles long. It should therefore be possible for a train starting from the top of this gradient to supply power to the overhead lines by working regeneratively for this long distance.

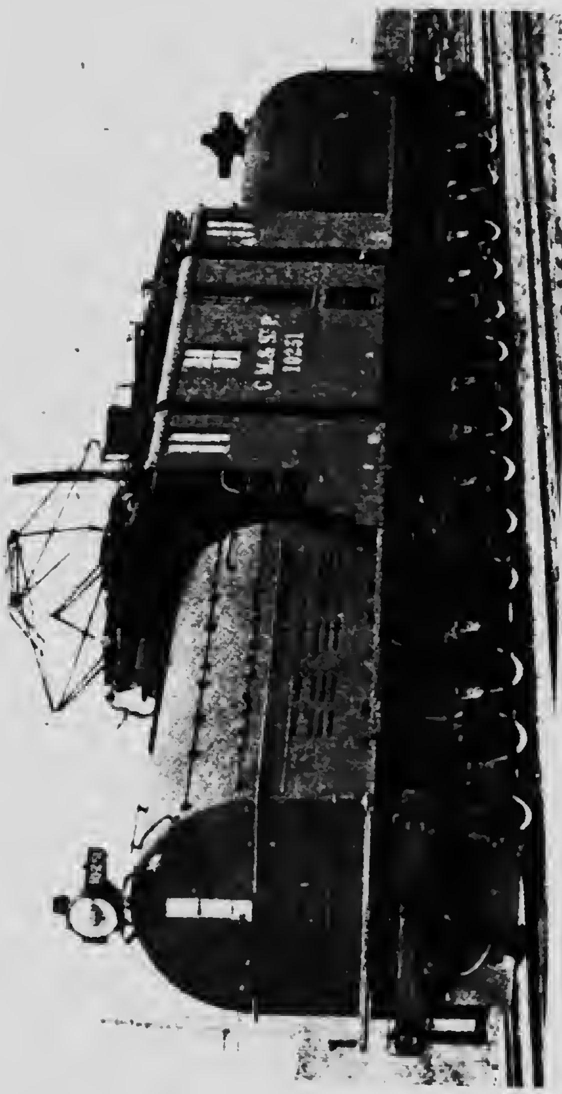
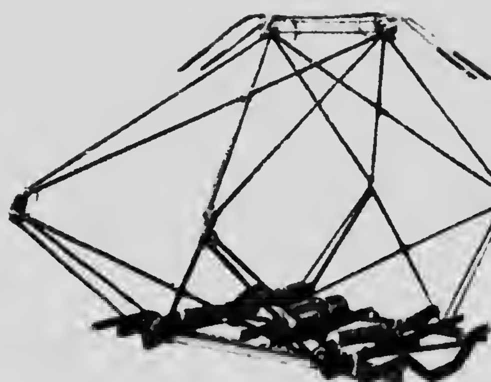


Fig. 1,012. Gearless Passenger Locomotive equipped for Regenerative Working.

An external view of one of the locomotives used for this regenerative working is given in Fig. 1,012. It presents a curious appearance to English eyes, being at first sight not unlike two steam locomotives back to back, an impression, however, speedily removed by an examination of the details. It is 76 ft. long over all and weighs 530,000 lb., or over 230 tons, and is capable of exerting 2,750 H.P. continuously, or 3,240 H.P. for one hour; it can start on a rising gradient of 1 in 50 with an acceleration of 0.48 mile per hour per second.*

Continuous current energy for ordinary working is supplied at 3,000 volts from twin overhead wires carried by catenary suspension. There are two collecting pantographs, shown in Fig. 1,012, which can be raised and lowered by pressure air, the valves being manipulated from the inside of the cab. One of these pantographs is shown separately in Fig. 1,013. It carries two sliding contacts made of copper and with renewable contact surfaces, and in this respect may be compared with the pantographs used on the N.E. Railway in England (*see* Figs. 1,720 to 1,722). Both sliding and rolling contacts have been tried, and it has been found that the wear of the trolley wire is due far more to the destruction of its material by arcs at the points of contact than to its abrasion by mechanical friction. In the present case, with two sliding surfaces on the pantograph and two supply wires, there are four contact points for each pantograph. The pantograph is adjusted to lift the wire slightly, thus ensuring firm contacts which may even be lubricated slightly with excellent results. With these arrangements the locomotive has been able to collect 2,000 amperes with one pantograph when running at 60 miles per hour without any arcing being noticeable at the contact points. At 3,000 volts this means 6,000 *kW.* being passed into the locomotive. The second pantograph is kept in reserve.



[illegible]

The locomotive in Fig. 1,012 will be seen to have 14 wheels on each side, in other words there are 14 running axles. Of these 12 are driving axles, there being no fewer than 12 bipolar c.c. motors on the locomotive. These, as in the case referred to on page 1,700 *ante*, are worked in groups of three motors in series, which share the 3,000 supply volts, thus handling 1,000 volts on each commutator at full speed. The control is such as to connect four, six and twelve motors in series for lower speed operation, an extension

* [illegible] speed in miles per hour during one second of [illegible] It may be noted that one mile *per hour per second* is equal to 1.47 feet [illegible] per second per second.

of series-parallel control which, as in the four-motor case described on page 1683 (Fig. 1,878), is made possible by the number of separate motors. The motors are gearless, the armature in each case being built upon the running axle, as shown in Fig. 1,914, which is a cross-section of the locomotive through one of the motor axles. It is instructive to compare this with the original locomotive designed in 1890 by Dr. John Hopkinson for the City and South London, the earliest electric railway. This also (*see* Fig. 1,642) had gearless bipolar motors, and a return to this type which was made by the New York Central some ten years ago is a tribute to the sound engineering instinct of the early designers. As might have been expected in view of the developments in dynamo design which have been made during the long interval, the bipolar field magnets of the modern locomotive are far more compactly designed than those of the earlier example. They are shown in Fig. 1,915, which is a diagrammatic side-view of a part of the locomotive showing four of the motors in section. The series magnetising coils are placed between the armatures, the magnetic flux being horizontal with successive fields magnetically in series.

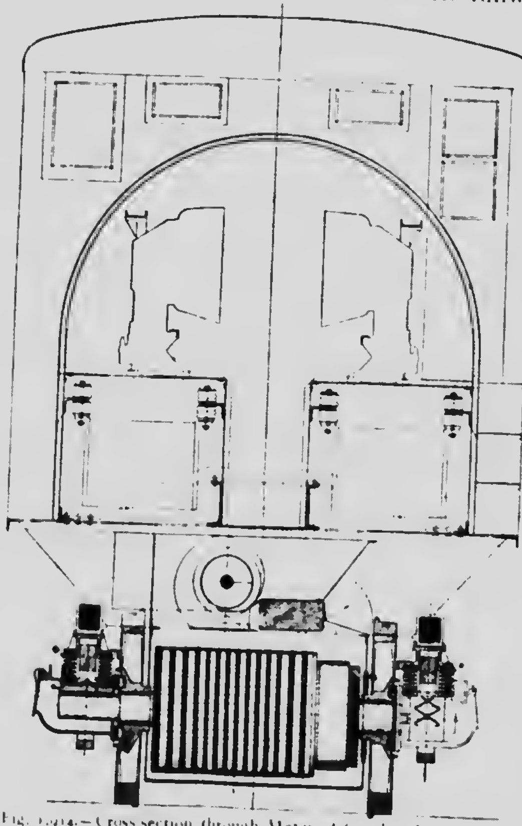


Fig. 1,914.—Cross-section through Motor of Gearless Locomotive.

We must not spend time in further details, but as bearing on the question of geared *v.* gearless motors, the curves in Fig. 1,916 are instructive. They are the efficiency curves at different speeds of the motors just described, and of geared motors on an earlier locomotive on the same service, similar except as regards the gearing of the motors. The efficiency curve of the gearless motors steadily rises with the speed, whilst that of the geared motors falls till, at 50 M.P.H., it is 10 per cent., and at 65 M.P.H. 22 per cent. below that of the gearless motors. The reasons for the fall are fairly obvious.

It is with these series motors available that a successful scheme of regeneration has been worked out. As already remarked (*see* page 1708) it is only possible for series motors to be utilised for regenerative working either by using a shunt winding in addition to the series winding or by separately exciting the fields. In recent times the second alternative has

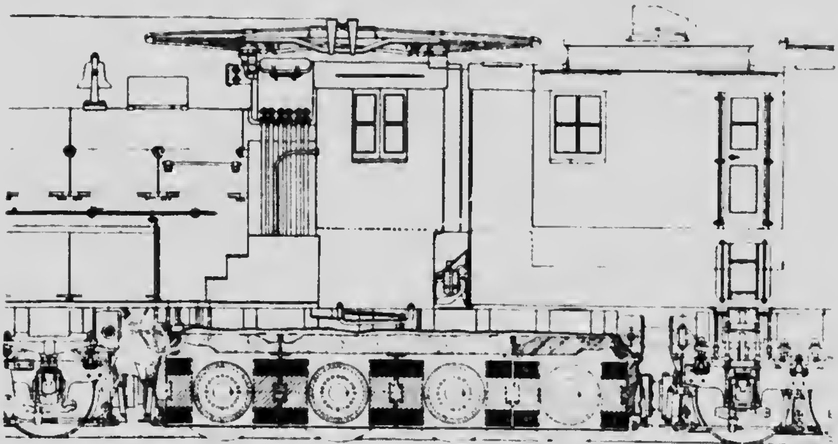


Fig. 1,915 Part Section of Gearless Locomotive showing Motor Armatures

been more usually adopted, the necessary exciting current being obtained from a small motor-generator set with excellent results. In the case now under consideration, with twelve generator motors available, it is found that eight are sufficient to supply all the braking effort and generator capacity required, leaving four of the main motors available to supply currents, as generators, for the excitation of the fields. This has the advantage of reducing the weight and complexity of the control apparatus.

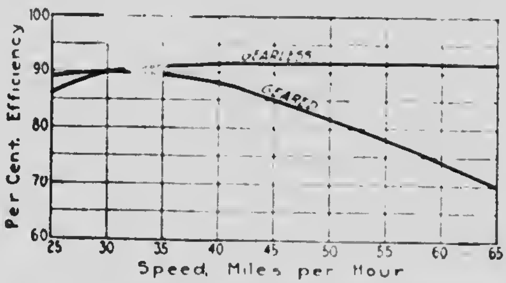


Fig. 1,916—Efficiency Curves of Geared and Gearless Motors

Some idea of the retarding forces which may be called into play may be obtained[1] from an inspection of Fig. 1,917, which gives to a speed base the tractive efforts of different combinations of these machines when working as motors. The curves marked T.E. (tractive effort) are for 12, 6, 4 and 3 motors in series, the whole twelve motors being used in all cases. For regenerative braking only eight motors are used, and therefore the curve for "four motors in series" is the most interesting, for this combination the ordinates must be reduced to two-thirds of the values shown when regarded as a braking effort. This braking effort would be reached for a particular speed with a lower current returned to the line than would be drawn from it for the motor effort, both because the E.M.F. of the machine would have to be higher (a result obtained by increasing the excitation) and because the losses are the other way round. Moreover, the four excitation machines would add something to the braking effort.

The results attained on a subsection of the line (Fig. 1,911) between Butte and Three Forks are exhibited in a series of curves in Fig. 1,918, in which the base is a time-line and not the speed-line of Figs. 1,916 and 1,917. This common base applies to all the curves; the ordinates are plotted to the different scales shown at the sides, and it should be carefully noted that these all start from different zero lines. The total load, including the locomotive, was 960 (2,000 lb.) tons, and the length of the trip 72.1 miles, the time taken being from 11.24 A.M. to 1.40 P.M., or 2 hrs. 16 mins.

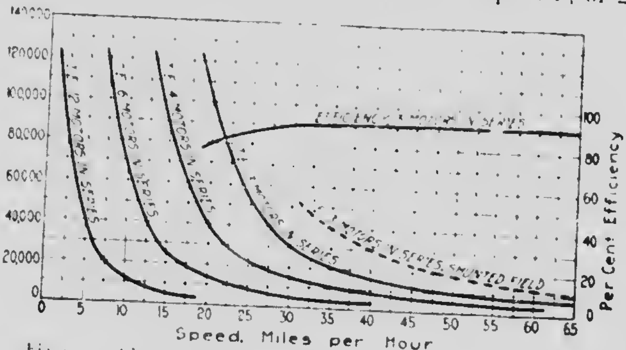


Fig. 1,917.—Characteristic Curves of the 12-motor Gearless Locomotive.

The lowest curve shows to the new base the height at each instant of the train above sea-level. The next curve to notice is that of the "trolley voltage," which, whilst the train is ascending, is seriously below normal. When, however, the train reaches the highest point and begins to descend, a time at which regeneration commences, the voltage, whilst the speed is kept fairly steady at about 20 M.P.H., rises above the normal, thus compelling the current to flow from the train towards the feeding points instead of in the opposite direction. As soon, however, as the speed is allowed to vary between wide limits the voltage fluctuates somewhat rapidly and sometimes violently. The speed curve comes next, and is an interesting one, but must be considered in connection with the remaining curve, the power curve, the zero line for which should be carefully noted. Ordinates above this line (+ ordinates) give the amount of power being drawn, instant by instant, from the trolley wires, whilst ordinates measured below the line (— ordinates) indicate that power of the scale value is being restored regeneratively to the line. The speed varies rather widely during the ascent, but during the latter part of the up grade is kept fairly steady at 30 miles per hour; for 45 minutes in the early part of the descent it is held also fairly steady at nearly 20 miles per hour, a large amount of energy being regeneratively returned to the line at the rate of about 1,000 *kw*. Towards the end of this period the speed is allowed to increase to about

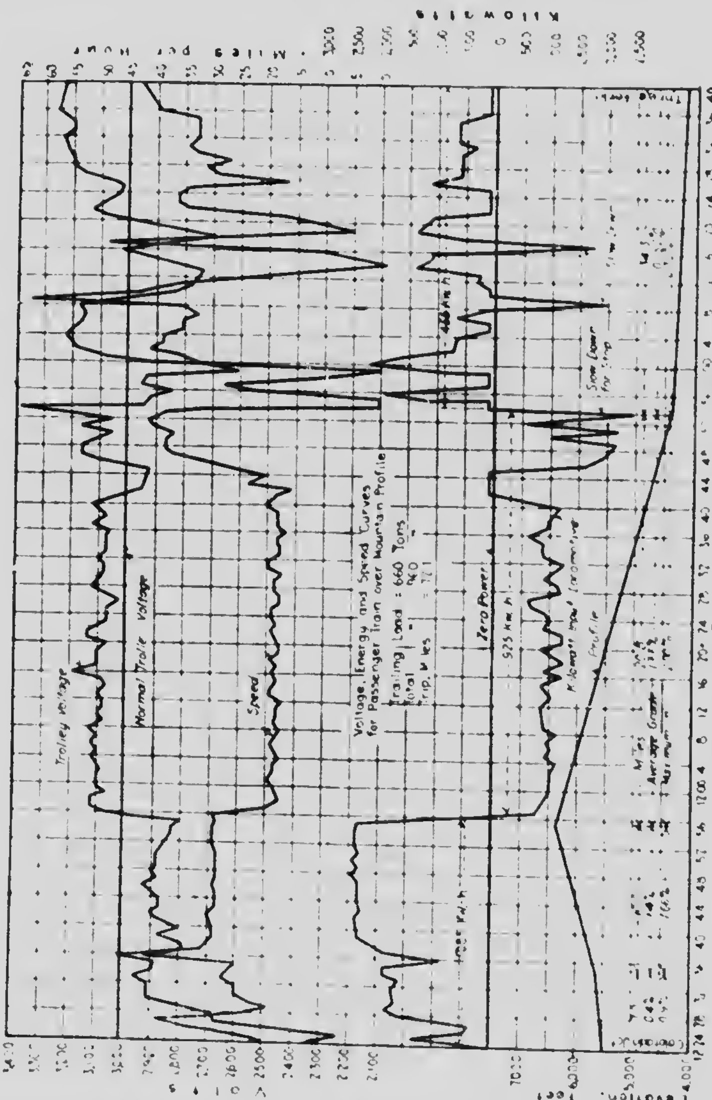


Fig. 1313.—Curves showing Results obtained with Regenerative Working

40 miles per hour, and just after this speed has been maintained for a few minutes, and whilst the train is being brought from it to a standstill, the rate of regeneration momentarily rises to 2,500 *kw*. There is, about five minutes

later, another stop, and then during the remainder of the record some rapid variations of speed power and voltage which will repay careful examination.

As a result of careful tests it is claimed that a train on a 2 per cent. grade has regenerated 42 per cent. of the energy required to pull the same train up the grade, and that on a 1·66 per cent. grade 23 per cent. has been regenerated. Moreover, an examination of the records of the entire Rocky Mountain division of the railway for one month for both passenger and goods trains shows that the regeneration was equivalent to 11·3 per cent. of the total energy used.

A.C. Regenerative Working. In *single-phase* A.C. traction the conditions for successful regenerative working are more difficult than in the

Fig. 1,913.—Sub-station on Norfolk and Western (U.S.A.) Railway equipped for Regenerative Working.

C.C. case, for account must obviously be taken of the phase as well as the voltage of the regenerated current if it is to return power to the line and absorb the energy of the descending train. It is obviously of no advantage to pump back into the line a heavy wattless current. The required result has been attained usually by the separate excitation of the motors, account being taken of the phase of the exciting current, but the methods are somewhat complicated, and a full and clear explanation would lead rather far afield.

When we turn to *three-phase working* the conditions are more favourable, as it is also in the case of the Norfolk and Western Railway (U.S.A.), described on pages 1007 *et seq.*, where three-phase traction motors are supplied with power from a single-phase distributing system. The actions there described are reversible, and therefore, when the train is running down inclines, the three-phase motors become asynchronous generators feeding back three-phase current into the phase converters, which transform it into single-phase current, the power of which can reach the line *via* the main transformer. For "regenerative working" the operation is so simple that it does not require any control equipment other than that already described. The manipulation of the master controller is exactly the same for "regeneration" as for "running." There is, however, one additional point which requires attention.

In traction working at periods of light load, it may happen, when some of the trains are standing still at stations and others are regenerating, that the regenerated power which is being returned to the line may be in excess of the load on the other parts of the system. This power will, in that case, find its way back to the generating station through the various sub-stations and transmission lines. For instance, in the case of the Norfolk and Western Railway just cited, the alternators generate current at 11,000 volts, 25 periods, but for transmission purposes the pressure is raised to 44,000, which is stepped down again to 11,000 volts at the sub-stations. An exterior view of one of these sub-stations alongside the railway track is given in Fig. 1,919. The 44,000-volt lines are brought in on and through the roof of the station, and the distributors for the trolley lines are taken out at the side through insulators, which can be clearly made out in the figure. All these arrangements resemble those already described (see pages 1224 to 1237). No attendant is required in the sub-stations, the oil circuit breakers in which are remotely controlled from adjacent signal boxes or passenger stations or from yard masters' offices. What we are here concerned with is the possibility of the regenerated power finding its way back to the power station at periods of light load when, if no other load were provided, it would reverse the generators and operate them as motors.

Fig. 1,920.—Water Rheostat at Generating Station for dissipating excess Regenerated Energy.

To prevent this happening, a loading device, shown in Fig. 1,920, is provided at the power station; it is constructed of electrodes immersed in a small canal which, for other purposes, runs alongside the station. The loading device is controlled by suitable switches, the operation of which is made automatic by a group of relays, magnetically operated switches, current transformers, etc. Thus, when the excess regenerated power reaches a certain value, say 300 *k*V.A., closing relays operate, and one of the water rheostats, of which there are two in the canal, is thrown on to the 11,000-volt busbars. The second rheostat is similarly thrown on when the excess regenerated power exceeds the capacity of the first rheostat, and the difference between the excess regenerated power and the capacity of the rheostats is supplied by the generators which are thus kept "on load." As the excess regenerated power diminishes the second rheostat is switched out, and the first rheostat follows when the excess power sinks to zero and all the rheostat load is being carried by the generators. The rheostat consists of a steel cone connected to circuit-breakers and suspended over a six-inch iron plate fixed at the bottom of the canal and connected to a copper plate embedded in the earth outside the canal. The distance in the canal between the electrodes of either rheostat can be varied by raising and lowering the corresponding steel cone.

V.—TRANSFORMING EQUIPMENT AND SUB-STATIONS FOR ELECTRIC TRACTION

In electric-traction systems it may be, especially in A.C. working, that the distribution voltage on the overhead or other conductor from which power is being picked up is different from the voltage for which the actual driving motors are constructed. The reasons for these differences have been fully explained elsewhere and need not be repeated here. The A.C. transforming devices, usually static tansformers, by which the voltage is lowered to that which can be handled by the motors, are usually carried on the locomotive or the train, and the details of their installation have also been described. The attention of the reader is merely directed again to the point here.

The more general case, due to the distances which frequently separate the moving vehicles on which the power is being utilised from the generating station, is similar to that which holds in the wider problem of the utilisation of electric power. To convey the power from the generating station to the consuming point, it is both convenient and economical to deal with long distances by high-voltage *transmission* lines, which supply the power at high voltage to sub-stations, in which it is transformed to power at a lower voltage and passed on to the *distribution* networks, from which the consumers or the consuming appliance tap it as required. The various systems for transmission, sub-station transformation and distribution have been fully described with much detail in Chapters XI. to XIII., *ante*, the various types of transforming apparatus having been dealt with in preceding chapters.

Two important developments in this connection were not, in the Chapters cited, treated in detail, as it was deemed more appropriate that they should be dealt with in this section, their application being at present, though not necessarily, confined to traction work. These are (i.) the large current iron-or steel-clad *mercury-arc rectifiers,* briefly mentioned on page 1091, and (ii.) *automatic sub-stations* to which there is a brief allusion on page 1320.

V(i.).—MERCURY-ARC RECTIFIERS

The properties of the mercury arc which allow it to be used as a rectifier for transforming A.C. into C.C. power, have been referred to in detail in Chapter X. (pages 1076 *et seq.*), where there will be found descriptions of various types of rectifier from which unidirectional currents up to about 80 amperes per rectifier can be conveniently drawn. In all the rectifiers there described in detail, glass containing vessels are used for the arc, and it is to the use of this material that the limitation of the current to 80 amperes in any individual rectifier is due, for with higher currents (*see* page 1078) the glass is softened and the bulb collapses.

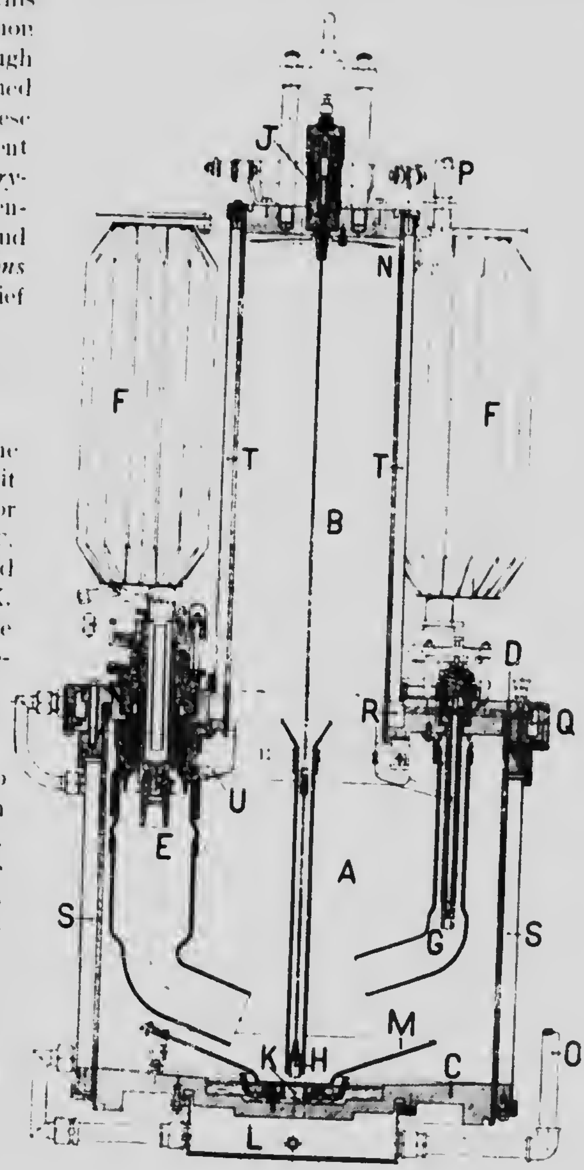


Fig. 1,641. Section of Large Mercury-arc Rectifier.

For larger currents other materials must be used for the containers and at the end of the section (page 1091) a brief reference is made to "steel-clad" rectifiers, for rectifying currents which can, amongst other applications, be utilised for traction purposes. Such rectifiers have been developed in recent years, both in America and in Switzerland, and therefore some little space may well be devoted to them here as supplementary to what has been set forth in Chapter X. (*loc. cit.*).

The arc, as previously explained, has to be formed in a fairly good vacuum, say, a pressure of about 0·012 mm. of mercury, and therefore the container must be practically air-tight, a condition not so easily maintained in a steel vessel with a removable cover as in a hermetically sealed glass bulb. Moreover, since steel is a conductor, the leading-in wires must be insulated from the vessel, and the bushes through which they enter must also be made air- or gas-tight. On the other hand, the use of metal in lieu of glass allows the container to be kept cool by water-jackets and other devices, by which the heat evolved in the process, which amounts to about 1·5 *kw*. for every 100 amperes of current, can be safely dissipated.

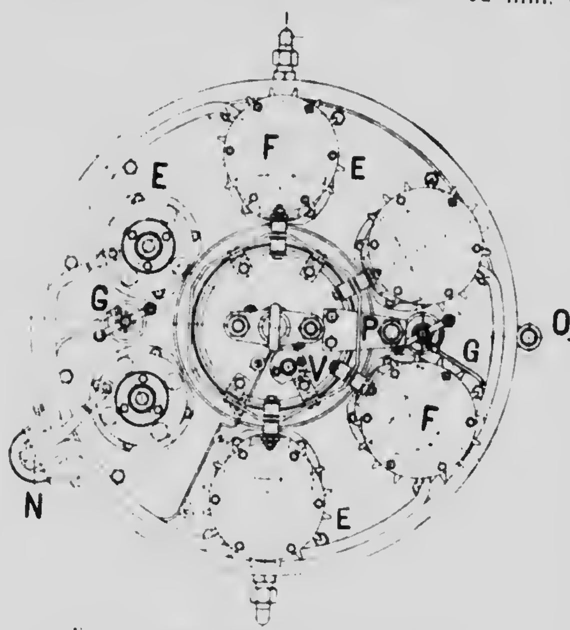


Fig. 1,922. Plan of Large Mercury-arc Rectifier.

Another difficulty which is much enhanced when heavy currents and high voltages are used, is the danger of short-circuits between the anodes, of which at least two must be used. Shields and guides for the various arcs have been devised to overcome this difficulty.

One of these steel rectifiers for dealing with currents up to 500 amperes in a single rectifier is shown diagrammatically in vertical section in Fig. 1,921 and in plan in Fig. 1,922. This rectifier is made by Messrs. Brown, Boveri & Co., at Baden, and is of 150 *kw* capacity. It consists of the same principal parts as a glass rectifier, namely, an arc chamber A (Fig. 1,921), above which is a condensing cylinder B; there are also the kathode K at the bottom of the arc chamber, and as many as six principal anodes E E E (Fig. 1,022) ranged round and above it.

The base and covers of the chamber are made of thick steel plates, as shown at C, D and N, and both N and D are water jacketed, as shown at S and T. The steel cover which carries the anodes has also water jackets O and R, the cooling water for all these jackets being brought in by the inlet pipe O, and carried away by the outlet pipe P. The mercury kathode K is contained in a shallow recess in the base, towards which a conical dish M draws the mercury condensed in the upper parts of the chamber.

One of the six principal anodes E is shown in section in Fig. 1,021, and a photographic view of its mounting is given in Fig. 1,023, the only discrepancy between the two figures being that the insulating shield which is one of the safeguards against short circuiting at the anodes is, in Fig. 1,021, shaped at the lower end to discharge towards the dish M, whereas in Fig. 1,023 the opening of the shield is vertically below the kathode. An important detail of the mounting of the anode is the mercury seal, designed to ensure that the joint through which the current is carried to the anode shall be gas tight. It is shown diagrammatically on an enlarged scale in section in Fig. 1,024. The shield S passes through the steel plate P, from which it is separated by a packing of asbestos at *b* and by a narrow cylindrical cavity *c* partly filled with mercury. The steel conductor *s*, clamped as shown, passes centrally through the stem of the shield, and another narrow cylindrical chamber, *c*, also partly filled with mercury, is interposed between the two. Another packing ring *d* separates the bridge supporting the anode from the steel plate. Experience has shown that this seal has completely solved the problem of holding the chamber gas tight when it has once been exhausted.

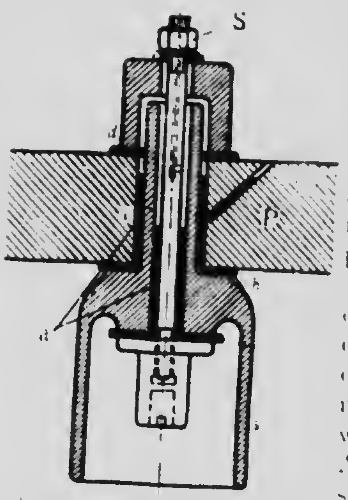


Fig. 1,024.—Mercury Seal for Anodes.

Fig. [illegible]—Anode of Rectifier.

As the total weight of this size of rectifier is about 1 150 kilogrammes, or well over a ton, it is obvious that the arc cannot be started by rocking or tilting the chamber, the method employed with the glass-contained rectifiers. For starting up, special accessories are therefore provided, consisting of an ignition anode H (Fig. 1,921), with special arc-striking apparatus. The anode is carried by a vertical steel wire, and usually rests about 10 mm. above the mercury of the kathode. This wire passes up to the cover of the condenser B, where it is suspended from the movable core of a solenoid I, the function of which is to control the movements of the anode H, so that it can be caused to strike an arc to start the rectifier when the latter has been lying idle for some time. Such an arc will immediately fill the upper part of the chamber with charged mercury ions, and the other anodes can then take up the running. For this arc a continuous current of about 5 amperes at 110 volts is found necessary. The connections for supplying this current from a secondary battery or from C.C. busbars are shown in Fig. 1,925, the action being started by pressing the button *d*, which springs back on being released. When the current passes, the solenoid *a* draws its core downwards and forces the ignition anode *b* into the mercury kathode *c*; the moment the contact is made the solenoid *a* and its series resistance R_2 are practically short-circuited, and the spring *f* being then stretched pulls the anode smartly out of the mercury, thus striking the arc and with it starting the action of the rectifier. The resistances R_2 and R_3 ensure that the currents passed shall not be excessive.

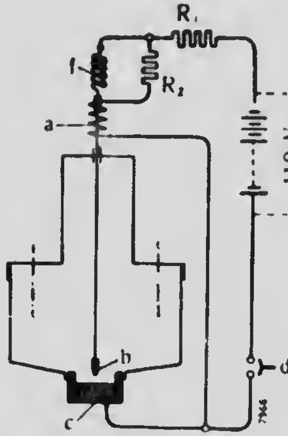


Fig. 1,925.—Connections for the Ignition Anode.

To provide for the conditions of electric traction, or other discontinuous service, two additional auxiliary anodes G G, known as "excitation anodes," are shown in Figs. 1,921 and 1,922. If the rectifier be mounted on a locomotive the demand for energy sometimes falls to zero, and even if installed in a sub-station the demand will fluctuate and at times be quite small. In these cases the arc in the rectifier will be extinguished and the rectifier put out of action until it can be restarted. Should this occur with the principal anodes, the auxiliary anodes, the distance of which from the kathodes is much less than the distance of the principal anodes,

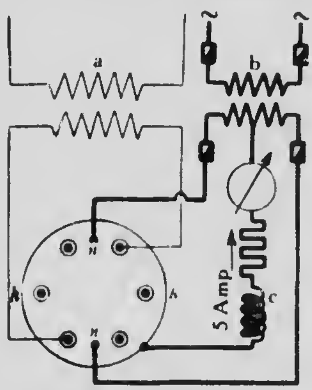


Fig. 1,926.—Connections for the Excitation Anodes.

will maintain the action. One method of doing this is to connect them to the secondary of an auxiliary transformer (or to taps on the main transformer), as shown in Fig. 1,926. In this diagram *a* is one phase of the main transformer, and *b* is an auxiliary transformer with its secondary joined to the two auxiliary anodes *n n* in the usual way, the kathode being diagrammatically represented by the outer circle *k k*, from which the continuous current, passing back to the mid point of the secondary, is drawn. By means of the choking coil *c* and resistances this current cannot exceed 5 amperes at the working voltage of the secondary. Thus, if the transformer *a* ceases to supply current to the rectifier through the principal anodes, the auxiliary transformer *b* will maintain the working conditions until the proper load is again required.

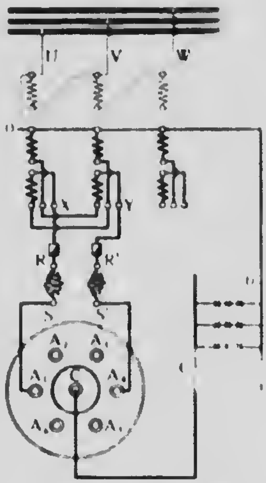


Fig. 1,927.—Connections for taking Oscillagrams.

Polyphase Working.—The rectifiers described in Chapter X. were all designed to work with single-phase supply currents, the unidirectional currents produced being pulsating currents rising and falling with the fluctuations of the alternating currents supplied. By the insertion of reactances on the unidirectional side (*see* Fig. 1,908 and elsewhere), the pulsating currents were not allowed to sink to zero, as that would extinguish the arc.

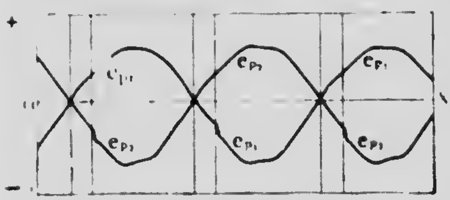
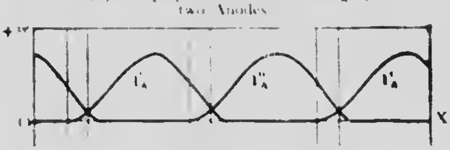


Fig. 1,928.—Superposed Voltage Oscillagraphs of two Anodes.

Fig. 1,929.—Superposed Current Oscillagraphs of two Anodes.



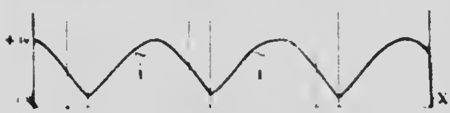


Fig. 1,930.—Sum of the two Currents.

The following oscillagraph curves, or oscillagrams, obtained experimentally by Messrs. Brown, Boveri & Co., show the effects of single phase and polyphase currents in actual practice. The curves were taken from one phase of a six-anode rectifier placed on a three phase supply, the connections being made as shown in Fig. 1,927, and the load C... being non-inductive. It should be noted that a modified zigzag method of connections is used for the coils of the transformer secondaries. The reactances used are shown at R S and R' S' on the transformer side of the rectifier instead of on the load side; in this position the effect is greater, but it necessitates a reactance in each A.C. rectifier lead which, as we shall see, is of advantage for good polyphase working. As many as 17 oscillagraphs were taken of currents and voltages at different parts of the circuits, and from these, those shown in Figs. 1,928 to 1,930 have been selected as sufficient for our purpose. Fig. 1,928 shows the superposition of two voltage oscillagraphs, of which one (e_a) is taken between O and X (Fig. 1,927), and the other (e_b) between O and Y. The graphs, of course, show phases 180° apart. Fig. 1,929 is also made up by the superposition of two oscillagraphs, one (i'_a) being the current in the anode A_1 (Fig. 1,927), corresponding to the voltage e_b in Fig. 1,928, and the other (i_a) being the current in the anode A_4 (Fig. 1,927). Each current eventually sinks to zero, but with a substantial time-lag behind the corresponding voltage, the effect being that before one current has fallen to zero the other has risen, starting from the moment its voltage has crossed the zero line; in fact, the loop of each current extends over considerably more than the 180° of the half period. An additional figure (Fig. 1,931) shows the pulsating current *i i i* through the load C O′ (Fig. 1,927), which would be obtained by adding together the three-phase currents *i′ i″ i‴*. The pulsations *i i i* are quite small.

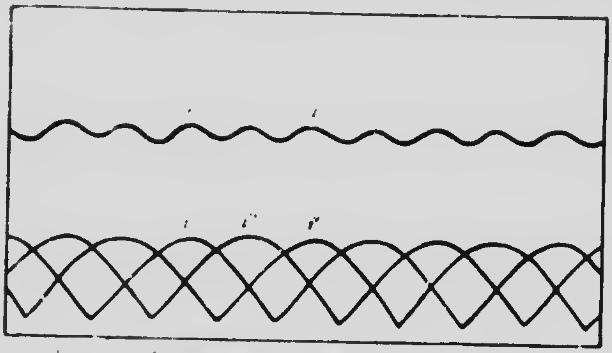


Fig. 1,931.—The Addition of the Currents from the Six Anodes.

When the six electrodes of Fig. 1,927 are used they are joined to the secondary of the step-down transformer of three-phase high voltage supply mains in exactly the same way as are the six slip rings of a rotary converter (see Fig. 1,913), the result being that when the currents from the six anodes are added together in the kathode circuit the resultant current, though still a pulsating current, is much steadier than the current depicted in Fig. 1,9[illegible], which was derived from a single phase. It is, in fact, made up of three such currents, *i i′* and *i ″*, displaced by the relative phase differences and added together as already shown in Fig. 1,931. The pulsations in the resultant current *i i* are very much reduced in amplitude relatively to either the mean or the maximum value as compared with the percentage amplitude of the current from two anodes shown in Fig. 1,930. The connections referred to are shown diagrammatically in Fig. 1,932, which, after what has already been said, is nearly self-explanatory. The blocks 1, 2, 3, etc., indicate fuses, and below them are the reactances R R R, which are wound upon the three limbs of a three-phase magnetic circuit, such as would be used for a three-phase transformer. The currents supplied to the rectifier are six-phase currents, and the reactances still further reduce the percentage magnitude of the pulsations, as shown in Fig. 1,031, because of the numerous phase displacements.

A still further reduction of the relative magnitude of the pulsations is obtained by splitting each of the phases of the six-phase current by using two sets of reactances, as shown in Fig. 1,033, and placing one of each of the two coils of the split-phase on the corresponding limbs of the two reactances. In addition to the two coils on each of the circuits of the three phase supply, each core of each three phase reactance is wound with an additional coil, known as a "compensating" coil, the two coils on the corresponding cores of the two reactances being joined in series to form a closed electric circuit. When working, the reactances of the currents in these closed circuit coils introduce a phase difference between the currents in the two branches of the split phase, and thus supply to the rectifier, which now has twelve anodes a twelve-phase current, with the result that the percentage magnitude of the pulsations of the unidirectional current is still further reduced. One of these reactances with its compensating coil as manufactured by Messrs. Brown Boveri & Co. for rectifier working is shown in Fig. 1,034, which, after what has been said above, requires no further explanation.

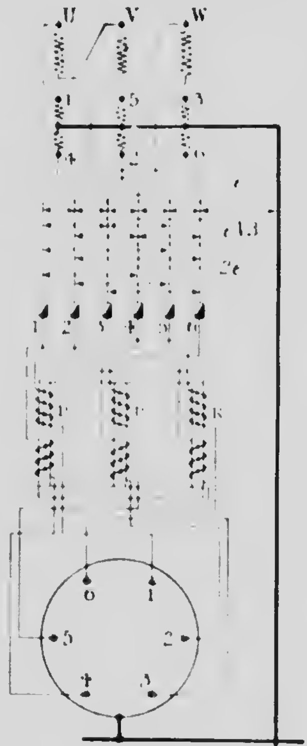



Fig. [illegible] Rectifier Working.

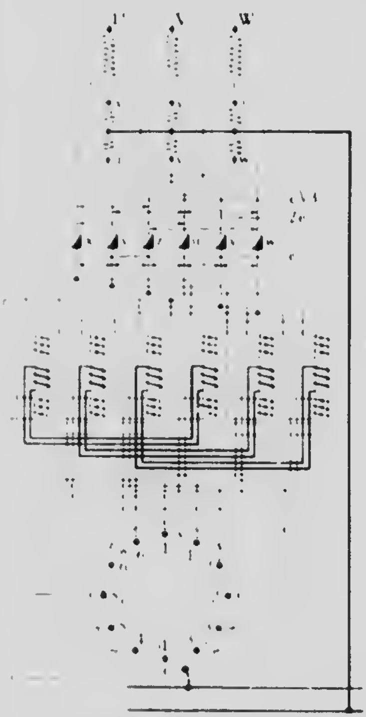


Fig. [illegible] Currents.

Efficiency. It has been explained in Chapter X. that the voltage drop (see page 1078) in a mercury-arc rectifier is constant at all loads, and that for the rectifiers there described is 15 volts; consequently the power lost for a given current is the product of the current by the voltage across the arc, and is independent of the voltage in the continuous current circuit. For the rectifier above described it is found that the voltage drop across the arc does vary slightly with the pressure at the terminals, its value being from 15 to 20 volts. In either case the efficiency rises rapidly with low voltages, and more slowly later. The efficiency curve is given in Fig. 1,935, in which the abscissæ are in hundreds of volts up to 1,200 volts, and the ordinates are in percentages of efficiency. It should be noted that at 1,000 volts the efficiency is 98 per cent., a value which, in transforming apparatus, is reached only by static transformers.

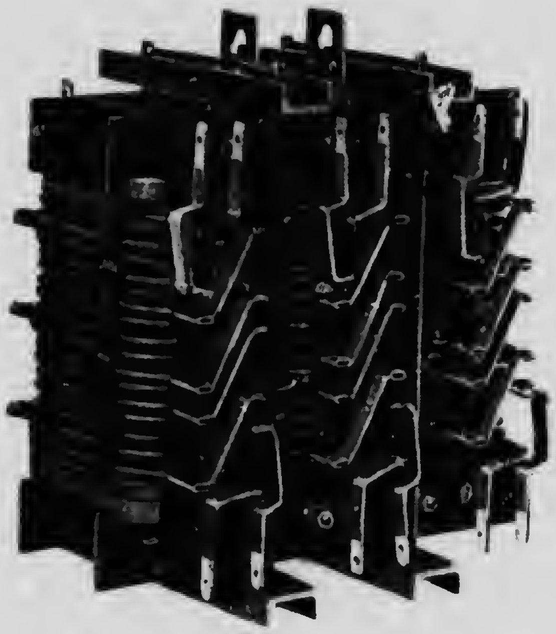


Fig. 1934. Reactances for Polyphase Currents.

We are now in a position to compare the efficiencies of the three types of substations commonly used for transforming

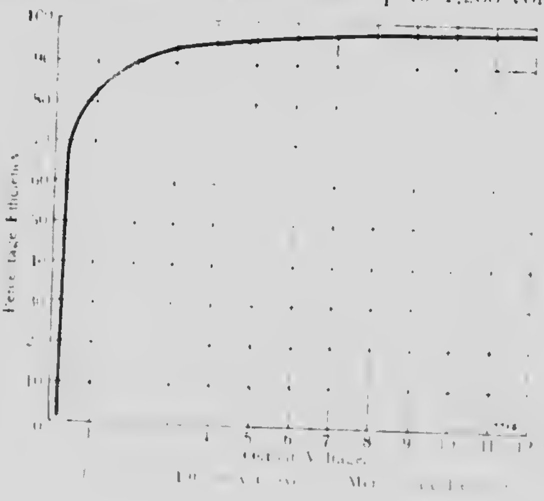


Fig. [illegible]

from high-voltage three-phase power to continuous-current power at the voltage commonly employed in tramway practice. The results are given in Fig. 1,036, in which the curves given are for three sub-stations each of 150 *kW* capacity, and receiving A.C. three-phase power at 15,000 volts and 50 ~ for transformation to continuous-current power at 600 volts. Curve (*a*) is for a station using mercury arc rectifiers, curve (*b*) for a station using rotary converters, and curve (*c*) for a station using synchronous motor generators (coupled plant). The efficiencies given are over-all efficiencies and take account of the losses in the step-down transformers. At low loads the advantages of the mercury arc rectifier are very marked, and it retains its superiority at full and over loads, though not so markedly.

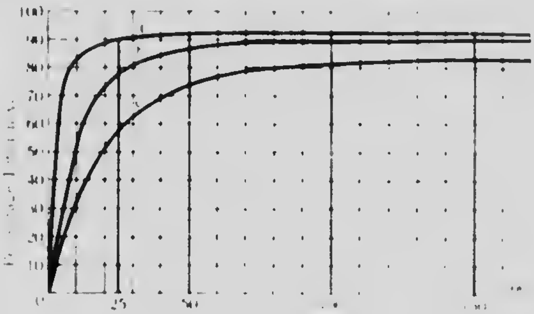


Fig. [illegible].—Comparative Efficiencies of three Methods of Transformation.

Standardisation. Rectifiers of the type just described are made by Messrs. Brown, Boveri & Co. in two standard sizes, one for currents of 250 amperes and the other for currents of 500 amperes continuous rating, for use at working pressures from 110 to 800 volts or, if required, up to 1,200 volts. Experiments show that even the latter pressure may, by modifying some details, be increased to 2,400 volts. A rectifier to carry 1,000 amperes at 750 volts continuous rating is being constructed, but no tests have yet been published.

Paralleling. The paralleling of transformers for cases such as that shown below in Fig. 1,041, raises interesting problems, which are not difficult to solve, because of the simplicity of the rectifying apparatus on the one hand and the flexibility of A.C. working on the other.

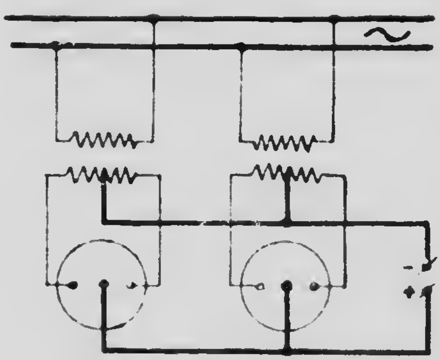


Fig. [illegible].—Two A.C. [illegible] with Separate [illegible]

As regards the rectifier itself, an increasing load could be provided for by increasing the dimensions of the electrodes to give increased current, or if the increase of load were caused by increase of voltage the distance between the electrodes could be increased to guard against the danger of flashing over. The usual case required in practice is for the D.C. voltage to be maintained constant and the load varied by varying the current. In other words, the rectifiers are usually required to work at constant P.D., but even if they were not the same spacing of the electrodes provides for a wide range of output voltage. As regards fluctuations of current, we have seen above that it has been found desirable to standardise on a maximum current basis. For currents heavier than the maximum on fluctuating loads it is found more economical to parallel as many of the standard rectifiers as may be required rather than to design larger rectifiers.

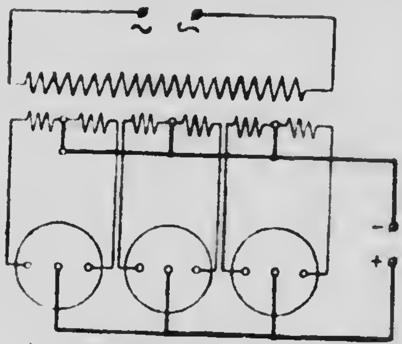


Fig. 1,0[illegible].—Three Arc Rectifiers on Single Transformer.

If each rectifier has a separate transformer, the paralleling simply requires the + and — terminals to be connected in the usual way, as shown in Fig. 1,037, the drop in the transformers securing a fair division of load without the use of a reactance. This arrangement also leads to less variation of voltage between light load and full load than if a single large rectifier were used, though the capital cost of several small rectifiers is greater than that of a single large one of the same maximum capacity. The same method is adopted and the same results follow if the main transformer has a single primary winding and several secondary windings, one for each rectifier, as shown in Fig. 1,038. Only single-phase connections are, for simplicity, shown in these diagrams, but the connections are applicable to the polyphase rectifiers described above and illustrated in Figs. 1,921 and 1,922.

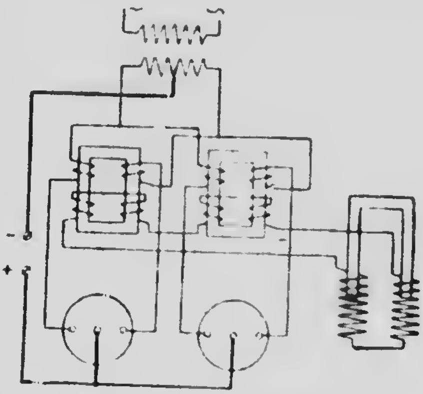


Fig. 1,039. Control with Variable Reactance.

For *voltage regulation* on variable loads advantage can be taken of the reactances, already described, as used in the six phase rectifiers (*see* Figs. 1,032 and 1,033). These reactances, it will be observed, are introduced into the anode, i.e. the A.C., leads. Increased flexibility of regulation can be obtained by using the "compensating" coils mentioned in connection with Fig. 1,033, which for this purpose should be joined up in series so that an overload on one of the paralleled rectifiers would be quickly adjusted by the action of the coils in the compensating circuit. Still greater control is afforded quite simply and economically by introducing a variable core reactance into the compensating circuit, such as is shown in Fig. 1,939, in which there are two rectifiers in parallel.

Many other arrangements are possible, but especial interest attaches to the "compounding" arrangement shown for a single rectifier in Fig. 1,940. It is recalled that the term "compounding" is used to connote the automatic regulation to constant P.D. at different loads by the direct action of the load current. In this case the pulsating load current on the C.C. side is utilised. The ordinary reactance R_1 has its compensating coils c_1 and c_2 connected in series across the anode leads a_1 and a_2 through an auxiliary reactance R_2, which, as shown, consists of three cores with the usual yokes. The windings on the two outer cores carry anode coils electrically in parallel with their M.M.F.s in series, whilst the central core carries a cathode coil, the C.C. current in which provides permanent magnetisation which rises and falls with the load. The central core, if unmagnetised, acts as a magnetic short-circuit on the other two cores, throttling the current in the compensating circuit, and therefore cutting down the *auxiliary voltage* (-|- or —) introduced by the compensating coils on R_1. As the load increases this central core becomes magnetised always in the same direction, and the throttling effect on the compensating circuit diminishes, so that at full load, if the auxiliary voltage be -|-, the drop caused by the increase of load may be wiped out or may even be reversed, the whole arrangement working with what we have elsewhere described as a *rising characteristic*, in other words, at full load the P.D. on the C.C. terminals is above the normal, and may be used to compensate for the drops in feeders on the distributing side.

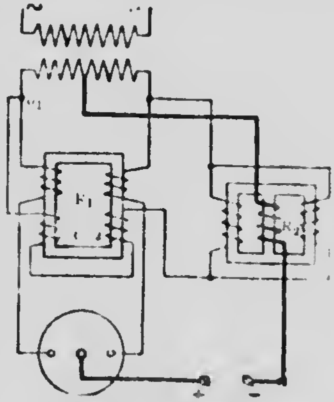


Fig. 1,940.—Voltage Compounding Regulation of a Rectifier.

The reader who desires to pursue the subject of the paralleling and regulation of mercury-arc rectifiers further, will find some useful information in an article in the *Electrical Review* for February 14, 1919 (page [illegible]), from which the above figures, 1,937 to 1,940, have been taken.

Equipments. A rectifier equipment, as erected at Berne, Switzerland, is shown in Fig. 1,941. It consists of three rectifiers of the 500 ampere type, and is designed for an output on the C.C. side of 800 *kw.* at 580 volts continuous rating. The rectifiers can be paralleled to give at full load 1,500 amperes at 580 volts. Details of the pipe system for the circulation of the cooling water, as well as other working details, can be made out in the figure.

The anode radiators R R (Fig. 1,923) are not used. That such rectifiers form now a serious factor in engineering work is evident from the fact that

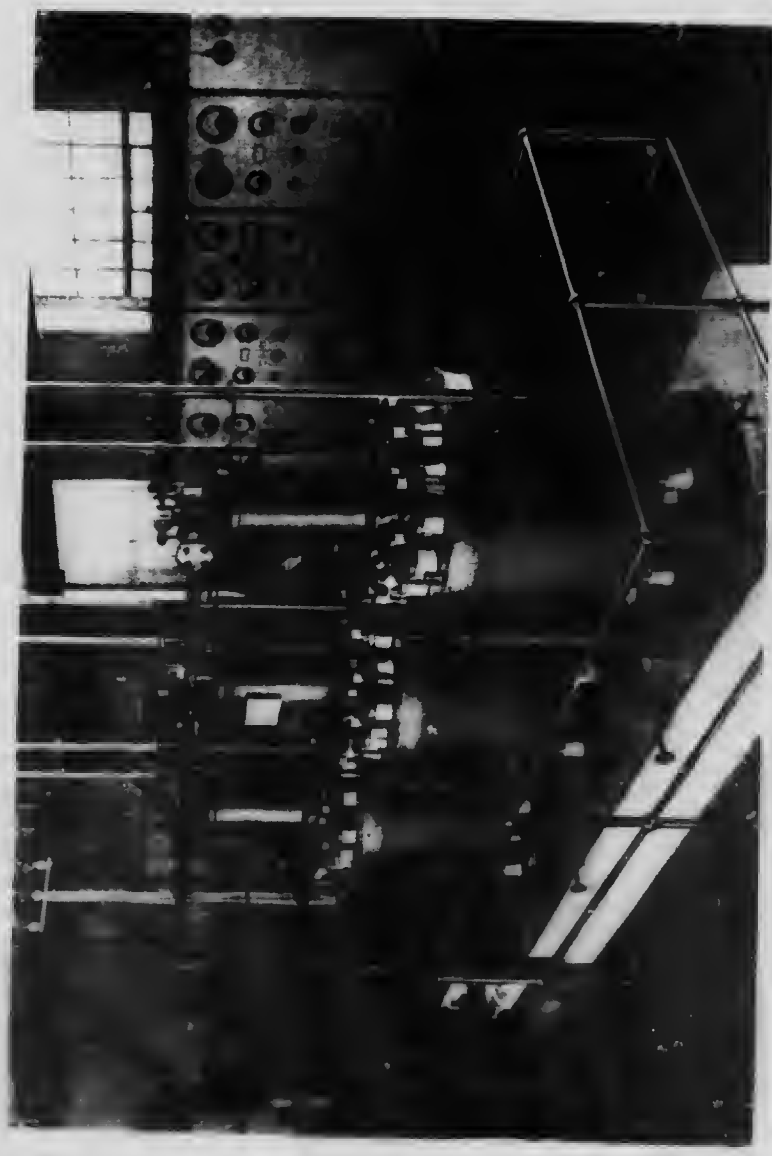


Fig. 1,924.—Mercury Arc R[illegible] Equipment in [illegible]

from Messrs. Brown, Boveri & Co.'s works alone, rectifiers installed in 125 separate equipments have an aggregate capacity of over 50,000 *kw.*

V(II). AUTOMATIC SUB-STATIONS.

In the chapter devoted to Generating Stations the consideration of the switching and controlling arrangements occupies a prominent position (see pages 518 to 574 *ante*), and where large currents or high voltages are utilised there have been developed, for reasons which are there fully set forth, various systems or methods of "remote" control in which in their present development only low voltage control circuits are actually brought to the operating switchboard, the real switches and operating and protective units being placed in more convenient and readily accessible positions but within the confines of the generating stations.

It was early obvious that where no running machinery was involved similar methods could be applied to the still more remote control of apparatus not in the generating station, but installed at convenient points of the distributing system. Thus static transformers could be cut in or cut out as required for varying conditions of load, and even in secondary batteries where end cell regulation was used (*see* pages 12[illegible] *et seq.*), the operation of cutting the regulating cells in or out could be similarly controlled from the generating station switchboard.

Simultaneously, and oftentimes in conjunction with the development of remote control switching systems, automatic apparatus for the protection of the circuits under abnormal contingencies had been developed and have been already dealt with in various parts of the book, but more especially in Chapter XIII (pages 1321 *et seq.*). The effect aimed at usually is to cut out or remove completely the threatened apparatus or section from the "live" circuits when a predetermined danger point is reached. What is not, as a rule, done is to restore the apparatus or section if and when the danger disappears.

The complete remote control, or the automatic working of a "kinetic" transformer sub-station involves the starting up as well as the stopping of moving machinery, and introduces a new set of problems which, at first sight, appear to be insoluble as the continued presence of human assistants would seem to be necessary to ensure the immediate running of the machinery as well as to manipulate the sometimes complicated series of operations required to start rotating transformers and to throw them into the working circuits when running at the proper speed and ready from an electrical point of view.

The advantages of completely automatic sub-stations, not even remotely controlled from the generating station, are greater in inter-urban tramway working than in generating and distributing systems where the demand, though variable, is at definite fixed points or over definite small areas. This arises from the fact that a particular system may not only extend over long distances, but that the supply of a large quantity of power may be demanded at any time at any part of the system, and that this particular part may also be for fairly long intervals on light or even no load. The main problem is to apply automatic controlling apparatus to the same operating units and accessories as are used in manually controlled sub-stations.

Early Sub-stations. The first automatic sub-station control equipment of this type was put in operation in 1914 in a sub-station of the Elgin and Belvedere (Illinois) Electric Railway. By May 1st, 1919, there were in operation in the United States thirty-five sub-stations completely controlled by automatic apparatus, two remote-controlled or, as they are called, semi-automatic sub-stations, whilst almost as many more were being equipped as rapidly as possible. It is therefore evident that practical engineers consider the problem to have been solved sufficiently well for everyday use.

Fig. 1,042.—Union Sub-station on the Elgin and Belvedere System, a Pioneer Automatic Sub-station (1914).

As being of historical interest, we give, from the *General Electric Review* an exterior view (Fig. 1,042) and an interior view (Fig. 1,043) of the Union Station of the Elgin and Belvedere Electric Company, the sub-station mentioned above as being the first automatically operated sub-station. The company at that time purchased power at 26,000 volts, three-phase, 25 ~, which it transformed to 600-volt d.c. power at three sub-stations. Each of these contained a 300-*kw* three-phase rotary converter, and the remaining two were, after a short experience with the first, equipped with the necessary apparatus and started operating automatically in August, 1915. We do not describe in detail the particular apparatus used in these early stations, as the development has been very rapid, and more modern apparatus will better repay consideration.

Later Sub-stations. The conditions to be fulfilled by the building which is to house the automatically controlled machinery are simplicity itself. Since it has not to be occupied by human beings for long periods of time, no minute provision need be made for the comfort of attendants, and the station need not be well lighted, artificially warmed, or otherwise made habitable. The waste heat from the running machinery should ensure that the temperature does not fall too low and beyond the necessary cubical space all that is required is good ventilation. Incidentally the exterior may be, without extravagance, designed to harmonise with the amenities of its surroundings as is presumably done in the sub-station building shown in Fig. [illegible], which is a view of an automatic sub-station at

Fig. [illegible].—Interior of a P[illegible] Automatic Sub-station

Fig. [illegible].—A[illegible] Automatic Substation in M[illegible]

South Butte, Montana, one of the sub-stations of the Butte Electric Railway.

A typical sub-station, as designed and erected for 1,000-*kw.* plant on the Chicago, North Shore and Milwaukee Railway, is shown in Fig. 1,045. This sub-station embodies the leading features which have been found to be desirable in American practice, namely, ventilating inlet openings near the foundations, with exhaust ventilators, the top of one of which can just be seen, on the roof. The lighting during the day time should preferably be

Fig. 1,045. An Automatic Sub-station on the Great Lakes.

from the roof, but as this is occupied by the high-voltage leading-in apparatus as well as by the ventilators, the windows are placed high up in the vertical walls, giving internally much the same effect as top lights, and leaving the lower parts of the interior walls available for the purposes of the sub-station. The roof is, of course, practically flat for convenience in the erection and maintenance of the incoming high voltage lines, some details of which can be made out on the figure, and will be understood from what has been said in the high voltage section. The outgoing heavy feeders for the neighbouring trolley lines can be seen leaving the sub-station at a convenient height on the left hand side. The whole external design, whilst satisfying all the requirements for practical working, has quite a pleasing effect.

Inside, the sub-station building has to provide the necessary accommodation for the usual parts of one or more complete transforming units, but in addition to the operating machinery it has to find room for the special automatic controlling apparatus which replaces the ordinary switchboard and its attendants. This does not demand a great amount of additional space. In fact, since the spaces round the machinery required for ease of access in manually controlled stations can be substantially reduced, the total cubical capacity of the building to house the same number of transforming units may even be reduced, especially in vertical height.

Sequence of Operations.—In a distribution system for supplying electric power to [illegible] the main function of a sub-station, whether manually or automatically controlled, is to maintain the voltage on the trolley wire or in the conduit at a proper working value, and when this voltage falls too low to bring the necessary or additional transforming machinery into operation; subsequently, when the load diminishes, superfluous machinery is to be cut out and shut down. In a *single unit* sub-station the sequence of operations for starting up will therefore be somewhat as follows:

(i) When the voltage on the trolley wire or distributing network falls too low a switch must be closed which starts a series of operations by which the rotary will be run up to its proper synchronous speed and its field circuits excited.

(ii) If the rotary, when running at the proper speed, has the wrong polarity this must be automatically corrected.

(iii) When the polarity is correct the brushes, if not already on the commutator, must be lowered and the [illegible] switch closed.

(iv) The [illegible] line switch is finally closed, paralleling the machine on to the distributing network; and finally,

(v) When the load sinks to a predetermined point for a definite time an underload relay, directly or indirectly, must trip the relevant circuit breakers, cutting out the rotary, which runs to a standstill, the brushes being raised ready for the next starting up.

The automatic apparatus must also protect the station against certain contingencies which may arise more or less frequently in practice, and which may require it:

(*a*) To cease to operate if the A.C. voltage is too low or if the phase rotation is wrong.

(*b*) To cut out the sub-station if the A.C. circuit is overloaded.

(*c*) To cut out the sub-station if the trolley wire voltage rises too high and the flow of power is reversed.

(*d*) To cut out the sub-station if the D.C. circuits are seriously overloaded for more than a prearranged definite time.