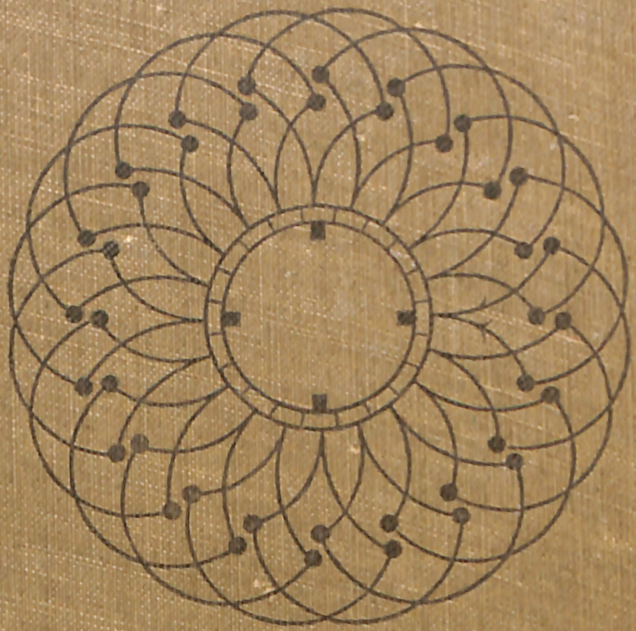
MODERN · ELECTRICAL · ENGINEERING ·



MODERN
ELECTRICAL ENGINEERING

MODERN ELECTRICAL ENGINEERING

PREPARED UNDER
THE EDITORSHIP OF
MAGNUS MACLEAN M.A. D.Sc.
PROFESSOR OF ELECTRICAL
ENGINEERING IN THE ROYAL
TECHNICAL COLLEGE GLASGOW

In Six Volumes: Profusely Illustrated with Diagrams and Plates

VOLUME IV

THE GRESHAM PUBLISHING COMPANY LTD.
66 Chandos Street, Covent Garden, London

CONTENTS

VOL. IV

14. INCANDESCENT LAMPS

15. ELECTRIC TRAMWAYS

15. Electric Tramways

INTRODUCTION

Definition and Origin of the Name.—A tramway, or, as it is termed in America, a "street railway", is a track of rails laid down in a public thoroughfare, on which cars are run for the conveyance of passengers, and, in a few cases, of goods.

The word "tram" originally meant a beam of wood, and in Scotland the beams of wood which are employed as the shafts of a cart are called the "trams". The word was also used to designate the longitudinal logs laid down in a road to facilitate the movement of wheeled trucks along it; and in the case of coal-mining the word "tram" has been applied to the trucks themselves.

The first use of iron for rails occurred in 1776, when James Outram, an engineer, to save the continual wear of the longitudinal timbers, fixed down iron plates on the top of them. Such lines became known as "Outram's ways", which led to the adoption of the word "tramway".

Historical.—The first tramway or street railway for passenger traffic was built in America in 1832, between New York and Haarlem; and in 1852 Loubat, a French engineer, constructed a tramway in New York the rails of which were of wrought iron and were rolled with a deep groove for the reception of the flanges of the car wheels; the rail itself was fixed down on to longitudinal timbers. The gradual development from this form of rail to the present type will be dealt with under the heading of Permanent Way.

Tramway cars were first drawn by horses, but, owing to the difficulty of hauling up steep gradients and covering a sufficient mileage per day, mechanical traction was early introduced. Steam cars were tried, but were objectionable in the centre of a town, and also were not economical for single units. Cable tramways were then adopted in some towns, as in Edinburgh and Birmingham.

Electric Traction.—Electric traction has superseded all other forms of traction on tramways, and is now almost universally adopted for this class of work. The first vehicle to be driven by electric power was built by Thomas Davenport, of Vermont, U.S.A., in 1835; and in 1838 Robert Davidson, a Scotsman, constructed a locomotive carrying a battery of forty cells, which supplied power to a form of electric motor.

It was not, however, along these lines that electric traction developed. The difficulty of obtaining a good, strong, and light portable battery prevented (as it still prevents) the use of accumulators to any great extent, and the systems finally adopted were those in which the electric current was generated at a power-station and conducted through cables or mains to the car routes, the current being led to the motors through a collector on the car which slides along a more or less continuous conductor to which the feeder cables are connected. There are three main systems, of which the first two are the most important, viz.: (1) The overhead-trolley system, which includes both the ordinary track system and the railless-trolley system; (2) the open-conduit system; and (3) the surface-contact system.

The Overhead-trolley System.—The most widely adopted system is that with a single overhead trolley wire above each track, the current passing from this line through the car motors and returning to the supply-station through the track rails. In some towns, owing to the magnetic disturbances set up by the fluctuations of the current in the trolley wires, and also to the corrosion, by electrolysis, of the gas and water mains due to leakage currents from the rails, the authorities have insisted on the erection of a double trolley line over each track, one for conducting the current to the cars and the other for the return circuit. Such a double trolley line must, of course, be used in the railless trolley system, which has the advantage of the cars not being confined to a fixed track, and also requires a less initial cost, due to the absence of the rails; the running costs are, however, greater, due to the extra tractive effort required to move the vehicles along, and to the expenses of tire renewals.

The Open-conduit System.—The open-conduit system has, principally for æsthetic reasons, found favour in many large cities, especially in the central portions. The conductors from which the current for the cars is collected are situated in a conduit or pipe beneath the surface of the track, and the collector on the cars, known as a "plough", passing down through a slot in the road, makes contact with the conductors underneath. The conduit may be placed at the side, under one of the running rails, as in Vienna, Berlin, Brussels, Budapest, and Bournemouth; or in the centre of the track, as in London, Paris, New York, Washington, Nice, and Bordeaux. The conduit system, except in one or two cases, possesses the advantage of the double trolley system, of not utilizing the track rails as the return conductor.

The Surface-contact System.—The surface-contact system was an outcome of the high cost of the open-conduit system, which caused inventors to endeavour to discover a system which had the advantages of the latter system and yet cost considerably less.

Of the many designs invented, only two or three have attained commercial success, among these being the Lorrain system, as at Wolverhampton, the Dolter system, at Torquay, and the "G.B." system, at Lincoln.

The subject of electric tramways will be considered under the following headings: 1, Dynamics of Electric Traction; 2, General Layout of a Tramway System; 3, The Permanent Way; 4, Rail Bonding and Welding; 5, Cables and Distribution System; 6, Overhead Construction; 7, The Open-conduit System; 8, Surface-contact and Other Systems; 9, Rolling-stock and Equipments.

CHAPTER I

DYNAMICS OF ELECTRIC TRACTION

General.—The problem of an efficient means of locomotion has always attracted a great deal of attention in the past, and we may be certain it will continue to do so in the future. It is a problem which is capable of many solutions, because in each particular case which is set before us the conditions differ to a greater or less extent.

In spite of the phenomenal development of motor-cars and motor-lorries, their sphere must always remain a limited one. For light loads they are admirably adapted, but for heavy loads at high speeds the running and maintenance costs are higher than those of vehicles running on a specially-prepared track, i.e. on rails. There is also much smoother running in the latter case. Hence it is that we have heavy cars running on tramways carrying great loads of passengers from one part of a town to another and away into the surrounding suburbs.

Speed-time Curves.—The problem of all systems of traction is to move a vehicle from one place to another, and in the case of tramways, as indicated above, this consists in moving the cars along rails specially laid down for the purpose. In the case of the railless trolley system, of course, the cars, or rather buses, move along the ordinary street or road surface.

Now, the motion of any moving body whatever can be represented by an equation, or, still better, by a curve, and in the case of tramway cars this curve is called a "speed-time curve". The general form of this curve may be deduced from the fact that all the cars go through a certain cycle of motions, which are merely repeated, more or less completely, over and over again.

Fig. 1 shows one such complete cycle of motions for a car operated by electric motors. The car first of all starts from rest and increases in speed, at first quickly and then more slowly, till it reaches a certain maximum speed. The maximum speed may or may not be maintained for a definite length of time, but ultimately the power is cut off and the car drifts or coasts till the brakes are applied and it is brought rapidly to rest.

In fig. 1, A–B is the period of acceleration,
B–C „ „ maximum speed,
C–D „ „ coasting or drifting,
D–E „ „ braking,

and finally, to complete the cycle, we may consider

E–F as the period of rest.

Having determined such a time-speed curve, the motion of the car is completely determined; it can only repeat itself, more or less completely, over and over again. The speed-time curve shown in fig. 1 is drawn for the car when running on a level track; the effect of gradients, as will be shown later, is easily allowed for, down-gradients evidently tending to increase and up-gradients to decrease the speed. The area of the curve gives the distance run over in the time considered, and it is evident, from a slight

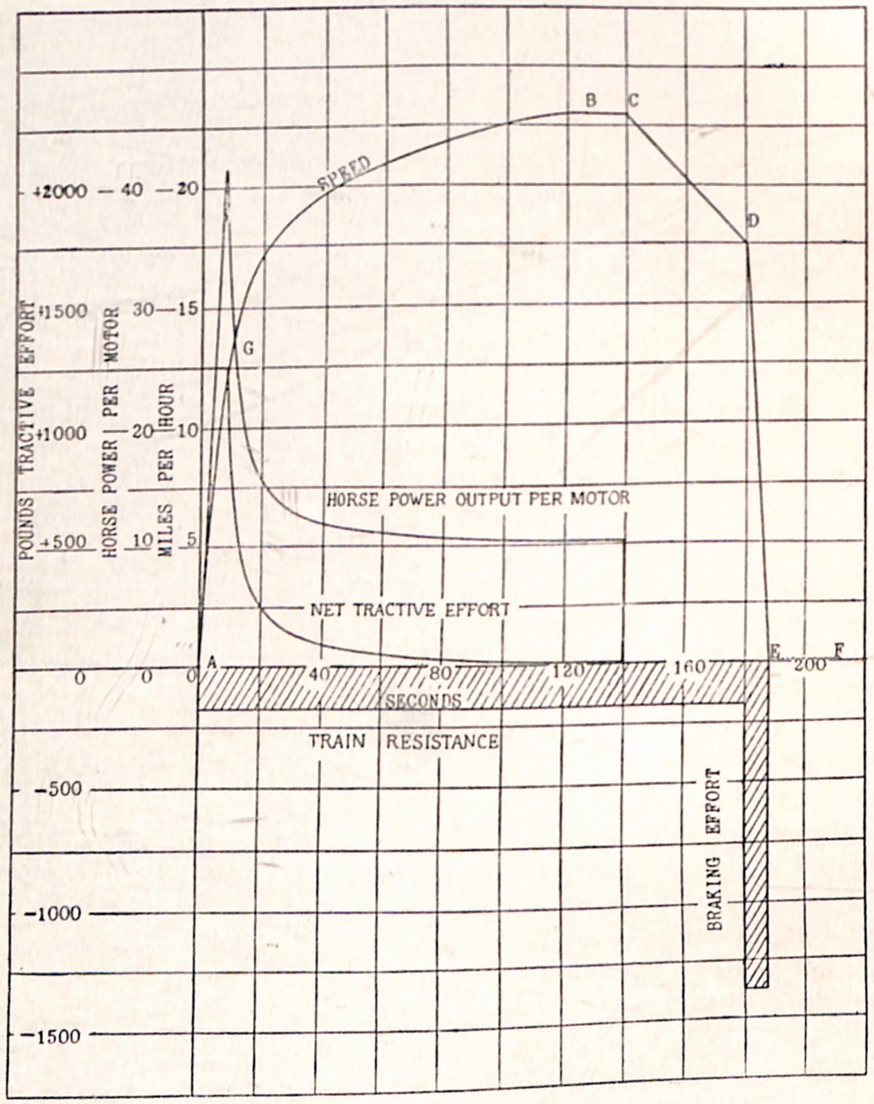


Fig. 1.—Speed-time Curve

consideration of the curve, that an increase in the acceleration will increase the area of the curve, or, what comes to the same thing, enable a given distance to be run over in a shorter time. For tramways, where the stops are frequent, this question of rapid acceleration is of extreme importance.

Special Advantages of Electric Traction.—Now it is due to the greater acceleration which can be obtained with electric traction that this form of traction has a distinct advantage over most other forms.

There are other advantages: we get a smaller weight for a given tractive

power, there are no fumes or smoke, and there is a suitable source of power for lighting the cars; but the outstanding advantage obtained with electric traction, as mentioned above, is that of greater acceleration. This is partly due to the better distribution of power over the axles, since in most cases all the wheels are driving wheels, but it is also due to the fact that the tractive effort, or force driving the car along, can be maintained fairly constant during the early part of the acceleration curve. This is obtained by what is known as the series-parallel control of the motors, together with a rheostatic regulation.

With most other forms of traction there is no efficient method by means of which this can be done, and thus we have then a very rapid falling off in the initial acceleration.

Tractive Effort required.—As a first step towards determining the speed-time curve for any route under any specified conditions we must be able to calculate the tractive effort necessary to drive the cars along the rails. The total tractive effort or force necessary for propulsion may be considered for simplicity as being made up of a number of parts. First, that required to overcome friction or resistance; second, that required to overcome gradients; third, that required to overcome curves; and fourth, that required to produce acceleration.

First, the tractive effort required to overcome friction or track resistance. This is somewhat difficult to arrive at, as it depends on so many things—on the speed, the condition of the track and the climatic conditions, viz. wind, snow, &c. Many empirical formulæ have been evolved to represent the resistance. The form of these formulæ is usually rather complicated, one of the simplest being evolved as follows:—

The causes of resistance may be thrown into three groups. First, those independent of the speed, as journal friction, rolling friction, and ordinary track resistance. Second, those depending directly on the speed, such as those due to flange action. Third, those which vary as the square of the speed, as air friction. We may thus write the resistance equation:

$$R = A + BV + CV^2,$$

where A, B, and C are constants. The constants are determined by actual tests on rolling-stock. R is usually given as so many pounds per ton, the total resistance being got by multiplying the value of R by the total tonnage of the car.

The number of empirical formulæ which have been evolved to represent the resistance is very great, and most of them are fairly approximate; the constants, however, should usually be obtained from tests made on a tramway as similar as possible to the one which is to be laid. A good average value to take for tramway work is 30 lbs. per ton. A closer approximation can be used afterwards when the power of the motors and the total weight of the cars and equipment have been determined.

Second, the tractive effort required to overcome gradients is equal to the product of the weight of the car and the slope of the gradient. If x represent the per-cent gradient, and W the weight of the car in tons, then the tractive effort required to overcome the gradient is $22.4\,Wx$.

Third, the tractive effort required to take the car round curves is, evidently, proportional to the curvature, and in practice is found equal to about

$$\frac{6000}{\text{radius of curve (feet)}} \cdot W = 6000\, W c,$$

where c is the curvature. This formula must be considered as only roughly approximate. It has been found impossible in practice to determine a satisfactory formula to represent curve resistance, since there are so many disturbing factors.

Fourth, and last, the tractive effort required to produce acceleration may be subdivided into that required for translational and that for rotational acceleration, or that required to accelerate the car as a whole along the track and that required to accelerate the rotating parts. The actual calculation of the forces required to produce acceleration is not difficult, being simply a problem in pure dynamics, but it is a somewhat lengthy piece of work. For simplicity the whole of the force required to produce acceleration may be considered as that required to produce translational acceleration alone, the effect of the rotating parts causing merely an apparent increase in the total weight accelerated.

The value of the tractive effort for acceleration purposes considered in this way is

$$\frac{2240}{g} \cdot \frac{88\,a}{60}\left(1 + \Sigma \frac{w k f}{2240 \,.\, W D}\right) . W.$$

In tramway cars the apparent increase of weight, due to the acceleration of the rotating parts, is about 10 per cent. The tractive effort for acceleration purposes is thus equal to

$$2240 \frac{1.1\,W}{g} \cdot \frac{88}{60} a = 112.3\, W a \text{ (lbs.)},$$

where a is the acceleration (miles per hour per minute),
g is the acceleration due to gravity (feet per second per second),
w is the weight of a rotating part (pounds),
k is the radius of gyration of the same rotating part (inches),
f is the ratio $\dfrac{\text{speed of the rotating part}}{\text{speed of driving wheels}}$,
D is the diameter of driving wheels (inches).

The maximum attainable value of the acceleration depends not so much on the tractive effort available as on the amount of adhesion between the driving-wheels and the rails, and this may vary from 15 to 30 per cent of the weight upon the driving-wheels, according to the condition of the rails—greasy, wet, gritty, &c. The maximum acceleration attainable will vary, therefore, from 3 to 6 miles per hour per second. In our calculations we can naturally only take the lower limit, viz. 3 miles per hour per second, and from this we find the maximum tractive effort required for acceleration purposes.

The total tractive effort required to move the car at any part of the

speed-time curve can now be written down as the summation of all the tractive efforts already considered. Thus we have the total tractive effort

$$T = W(R + 22.4x + 6000c + 112.3a) \text{ (lbs.)}.$$

Just at starting the friction is static and so cannot be deduced from the formula. It varies from 1 to $1\frac{1}{2}$ times its rolling value. Immediately after starting its value falls to that given by the formula, being, however, somewhat higher than that calculated at low speeds, say those below 2 miles per hour.

Horse-power required.—The horse-power required to drive the cars is determined directly from the tractive effort by combining it with the speed; thus (noting that a speed of 1 mile per hour is equal to a speed of 88 feet per minute),

$$\text{Horse-power required} = \text{H.P.} = \frac{88}{33000} T V = .002667\, T V,$$

where T = total tractive effort required (pounds),
and V = speed in miles per hour.

Evidently, when the maximum speed is attained, the acceleration will have fallen to zero, and we then get the horse-power required to take a car of W tons weight up an incline of x per cent at a constant speed of V miles per hour, provided the track be straight, as follows:—

$$\text{H.P.} = .00267\, W V (R + 22.4x).$$

The figures shown in the following table have been calculated from this formula, and are applicable to ordinary tramway working, R being taken as equal to 30 lbs. per ton.

Horse-power per Ton Weight required to take a Car up Various Gradients at Various Speeds

Per Cent Gradient.	Miles Per Hour.									
	5.	10.	15.	20.	25.	30.	35.	40.	45.	50.
0	0.40	0.80	1.20	1.60	2.00	2.40	2.80	3.20	3.60	4.00
1	0.70	1.40	2.10	2.79	3.49	4.19	4.89	5.59	6.29	6.99
2	1.00	1.99	2.99	3.99	4.99	5.98	6.98	7.98	8.98	9.97
3	1.30	2.59	3.89	5.18	6.48	7.77	9.07	10.37	11.66	12.96
4	1.59	3.19	4.78	6.38	7.97	9.57	11.16	12.76	14.35	15.95
5	1.89	3.79	5.68	7.57	9.47	11.36	13.25	15.15	17.04	18.93
6	2.19	4.38	6.58	8.77	10.96	13.15	15.34	17.54	19.73	21.92
7	2.49	4.98	7.47	9.96	12.45	14.94	17.43	19.93	22.42	24.91
8	2.79	5.58	8.37	11.16	13.95	16.74	19.53	22.31	25.10	27.89
9	3.09	6.18	9.26	12.35	15.44	18.53	21.62	24.70	27.79	30.88
10	3.39	6.77	10.16	13.55	16.93	20.32	23.71	27.09	30.48	33.87

Electric Traction.—The above calculations of tractive effort and horse-power required are purely dynamical, and apply, more or less, to all forms of traction, no matter what the motive power may be. We come now more particularly to the question of electric traction; and when adopting electricity as a motive power we must first of all decide what system of supply it is best to use.

There are continuous-current and alternating-current systems, the latter being sub-divided into polyphase and single-phase systems; and there is also the question of the supply voltage to be considered, and in the case of alternating currents the question of the best frequency to adopt. We shall only consider, however, the continuous-current system of traction, and this because it is almost the only system used to operate tramways. This does not, of course, refer to the generation and distribution of the electrical energy, but merely to the actual energy supplied to the car motors.

The Continuous-current Election-traction Motor.—The first thing to be considered is the form of electric motor which should be used for traction purposes. There are two important types of continuous-current electric motor, viz. the shunt motor, which has the field-magnet windings connected in "shunt" across the armature windings, and the series motor, which has the field-magnet windings in "series" with the armature windings. Now these two types of motor have very different characteristics. When supplied with current from a constant-current supply the shunt motor runs at approximately the same speed at all loads.

The series motor, on the other hand, drops rapidly in speed as the load increases. Again, the torque exerted by the shunt motor is roughly proportional to the current required to drive it, while the torque exerted by the series motor is nearly proportional to the square of the current which passes through it (see fig. 2). Now, though in many cases a constant-speed motor is desirable, if not absolutely necessary, what is wanted for traction work is a motor which will cause a minimum fluctuation in the current taken to drive it under the general conditions of service. To do this the speed going up hills must evidently be less than that on the level. Very great torque is also desirable, especially when starting on an up gradient and also when going up a steep incline. A considerable sacrifice of speed when going up hills is of slight importance compared with the great gain attained by keeping down the excessively heavy currents which would otherwise be required. It will thus be seen that the series motor is much better adapted to traction work than the shunt motor. The result of the improved load-factor—or ratio of average to maximum demand—which is got by the use of series motors is that somewhat lighter cables and contact-line conductors will do if the same margin of safety be allowed for. The series motor can also be made lighter, as the heating is less than with a shunt motor.

In practice it is found that the shunt windings—owing to the greater number of turns and the comparatively small wire used—are more liable to get out of order than series windings, especially when the motors are working under such conditions as obtain with ordinary traction motors.

The series motor is also capable of withstanding for a short period the full voltage suddenly applied to the terminals, with no external resistance

in circuit, a thing which no shunt motor could possibly be subjected to without being seriously damaged.

Regenerative Control.—One thing in favour of the shunt motor is that it can be used to supply current back to the line when the car is running by its own weight down a hill. This generation of electric current by the motors, besides lessening the power required from the generating station, has a braking effect on the car, and thus controls the speed within

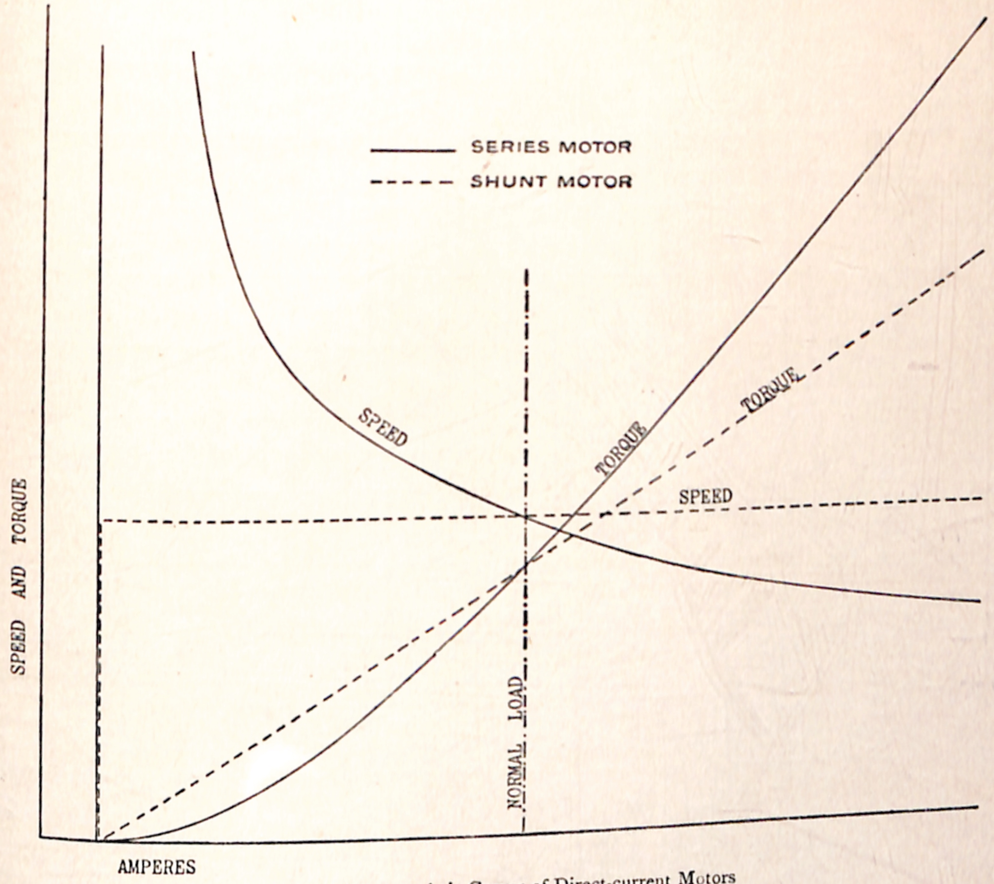


Fig. 2.—Characteristic Curves of Direct-current Motors

certain limits. This system of speed control is known as "Regenerative Control".

The objections to this system of control, in addition to the disadvantages of the shunt motors enumerated above, are, viz.:

First: The motors require to be made larger than would be otherwise necessary, due to the extra heating, especially in the field windings, which are always in circuit.

Second: The control is dependent on the overhead line being in order and the supply voltage not being interrupted; and, as both of these things may fail, such a system of braking is not so reliable as the ordinary rheostatic brake, which simply consists in short-circuiting the motors through a resistance.

Third: Unless the routes are fairly hilly, such as are found only in exceptional cases, or on mountain railways, the saving in power is not sufficient to counterbalance the increased cost of installation.

Characteristic Curves of Series Traction Motor.—Fig. 3 shows the characteristic curves of a standard series tramway motor. The curves are obtained partly from actual tests made on the motor itself and partly from calculations based on these tests. From these characteristic curves the

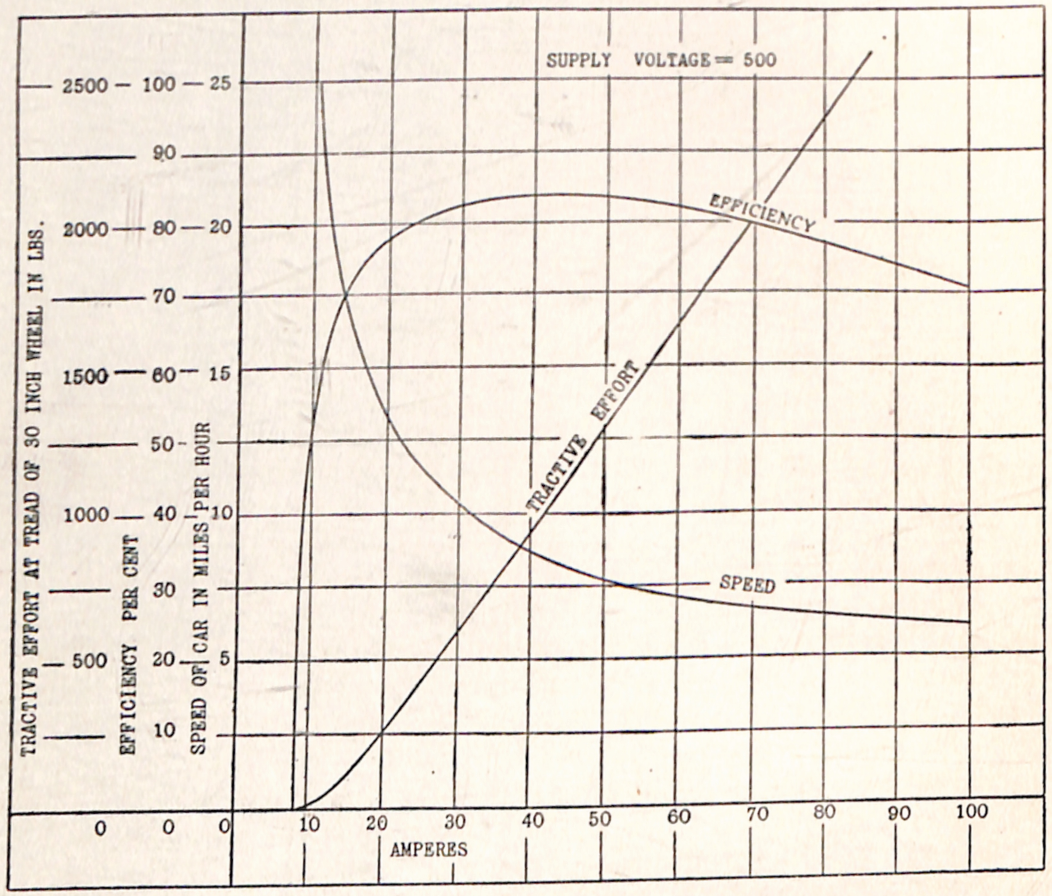


Fig. 3.—Characteristic Curves of 30-Horse-power Series Motor

Car wheel, 30 inches diameter; gear ratio = 4.86.

performance of the motor under the various conditions of service can be predetermined.

The motors usually drive the car wheels through spur-gearing, and it is an important matter to determine the tractive effort produced by the motors at the tread of the driving-wheels.

This is determined as follows:—

The horse-power given out by the motors $= \dfrac{\mathrm{N\,V\,I}\,\eta}{746}$,

where N = number of motors on the car,

V = volts applied to motor terminals,

I = current through motor (amperes),

η = efficiency of motor.

If now n = speed of motor (revolutions per minute).

r = gear ratio of motor $= \dfrac{\text{speed of motor}}{\text{speed of driving-wheels}}$,

and D = diameter of driving-wheels (inches),

then speed of car $= \dfrac{\pi \mathrm{D} n}{12 r}$ (feet per minute),

and as the horse-power $= \dfrac{\text{tractive effort (lbs.) speed (feet per minute)}}{33000}$,

therefore " " $= \dfrac{\mathrm{T}\,.\,\pi \mathrm{D} n}{33000\,.\,12 r}$,

and from above, this $= \dfrac{\mathrm{N\,V\,I}\,\eta}{746}$.

We get, finally, that the tractive effort produced by the motors at the tread of the driving-wheels

$$\mathrm{T} = \frac{33000\,.\,12 r}{\pi \mathrm{D} n} \cdot \frac{\mathrm{N\,V\,I}\,\eta}{746} = 168.7\,\frac{\mathrm{N\,V\,I}\,\eta r}{\mathrm{D} n}.$$

Considering each motor independently, it is evident that the tractive-effort curve for each motor can be calculated from the above equation for each value of the current, the supply voltage, the efficiency, speed, and particulars of the gear being known (fig. 3).

Completion of Speed-time Curve Calculations.—The speed-time curves can now be drawn as well as the current taken at every instant.

Note that at starting the motors generate no back-electromotive force, and hence the starting current is simply equal to the supply voltage divided by the resistance of the motor circuits. From this current the starting torque exerted on the car can be found by reference to the torque curve given in fig. 3. Equating this value of the torque so found to the value of the torque required, as already calculated from friction, gradient, &c., we are able to determine the initial value of a or the acceleration.

Consider now this acceleration as constant for, say, one second, or less if we desire a closer approximation, then at the end of this time we shall have a certain known speed, and this speed produces a back-electromotive force. The effect of this back-electromotive force is to reduce the current.

If the only resistance in circuit were the internal resistance of the motors, the reduced value of the current could be obtained directly from the speed curve shown in fig. 3, at least if it were prolonged sufficiently far to the right. To keep the starting current down, however, an external resistance is always inserted in the motor circuits. This resistance not only reduces the initial current but also the initial torque, and hence the acceleration. Proceeding as before, however, we can get speed after one second with this resistance in circuit.

Now the increase of back-electromotive force depends only on the current and the increase of speed, and not on the absolute speed. We can find value of current after one second, therefore, as follows: Add increase of speed after one second to speed of motor, on curve, which corresponds to the initial value of the current. The value of the current on curve opposite this increased value of the speed is equal to the new value of the current required.

Having got the value of the current after one second of time we get the corresponding torque, and hence a new value for the acceleration during, and the velocity after, the second second. Proceeding in this way the speed-time curve during acceleration can be drawn for any given value of external resistance in the circuit (fig. 1).

As the car gains speed the acceleration falls to zero, and we then get the value of the torque required to maintain the maximum speed. From this torque we get value of current required to maintain the maximum speed and the maximum value of the speed itself, by means of the curves shown in fig. 3.

To maintain the acceleration and the current fairly constant during the earlier part of the acceleration curve the motors are usually connected first of all in series with a fairly high resistance, say 10 or 12 ohms, in circuit. As the car gets up speed this resistance is gradually cut out. The motors are then thrown in parallel with most of the resistance again inserted, this resistance being finally cut out. This is known as "series-parallel control".

It should be noted that, as a rule, there are two motors on a tramway car. Each motor will, therefore, exert only one-half of the total torque required.

The drifting or coasting line of the curve is got by equating the total required torque to zero, and reversing the sign of the track-resistance and curve-resistance components.

The braking part of the curve, if caused by simply short-circuiting the motors through a resistance, can be determined in a somewhat similar way to the acceleration curve. A curve of retarding force instead of torque must be drawn first for the motor, since the losses in the motor lessen the torque but increase the value of the retarding force. Note also that the track resistance helps to retard the car.

If electromagnetic track braking or pneumatic braking be used, evidently the retarding curve will take a slope depending on the total frictional force exerted, and could approximately be determined therefrom. It is better, however, to assume a certain retardation, say 2 feet per second per second, and endeavour to attain it by a suitable form of brake.

From the speed-time and current-time curves, when constructed for various conditions of track, rolling-stock, system of supply, and service, the cost of power and the average speed per run, &c., can be readily determined.

In addition to the consideration of the calculations required to determine the speed-time and current-time curves, many other dynamical problems occur in connection with traction work, as, for instance, the effect of centrifugal force at curves. These problems will be considered later under the headings of the General Layout of a Tramway System and the Permanent Way.

CHAPTER II

GENERAL LAYOUT OF A TRAMWAY SYSTEM

General.—The tramway routes will almost entirely be determined by the position of the existing streets and the traffic along them; still, even then, great care must be taken in the choice of the routes, so that there will not be any greater congestion than is necessary on any of the streets in the centre of the system, while at the same time the requirements of the travelling public are, as far as possible, catered for. There is a certain latitude of choice, however, in the routes for the extensions, since the traffic will ultimately become diverted and increased along them.

System of Electric Distribution.—The electric current for driving the car motors is supplied at a pressure of from 500 to 600 volts. The current is either generated direct at this pressure, or, in the case of large systems, it is generated as three-phase alternating current at a high pressure, usually 6600 volts, and issued to sub-stations situated at various parts of the tramway system. At the sub-stations the three-phase high-pressure current is converted to continuous current at a pressure, as already stated, of from 500 to 600 volts.

It is not advisable to have current supplied to the car motors at a pressure less than 400 volts; hence, once the distribution of the cars on the system (under the heaviest service conditions) is given, and the current required by them is known, it is a simple matter to determine the best method of laying out the feeder-cable system, and also in which cases it will be more economical to have a high-tension system of distribution with sub-stations rather than to generate direct at the lower voltage. These matters will be found more fully dealt with under the heading of Cables and Distribution System.

Size of Gauge.—The question of the size of gauge to be used is of less importance for a tramway than for a railway. The "gauge" is the distance between the two running rails, and is measured from the inside edge of the "head" or "tread" of one rail to the inside edge of the other. There are two principal sizes of gauge used in practice—the standard railway gauge of 4 feet 8½ inches and the narrow gauge of 3 feet 6 inches. The broader gauge is better for large heavy cars, since it is conducive to greater stability, and also allows room for heavier motors and gearing between the car wheels. For small light cars the narrow gauge is well suited, the permanent way costing somewhat less in the latter case.

The Choice of the Routes.—The choice of the streets along which the tramways are to be laid is, as already mentioned, influenced by the requirements of the traffic. The broader the street the more suitable is it, naturally, for the reception of a tramway line. In modern towns, or in the newer parts of older towns, where the principal thoroughfares consist of fine broad streets, we have the most favourable conditions, and the routes are easily chosen; but in the centre parts of the older towns, where the busiest streets are usually narrow, one is often compelled to put the lines, not in the principal streets themselves, but in those at a small distance from and parallel to them. It is sometimes even necessary, to avoid the obstruction to the traffic which a double line would cause, that one line be laid in one street and the other in the next street parallel to it, the ends of the two lines being joined together by a loop. The cars in each street will then travel always and only in the one direction.

Arrangement of the Track Network.—It is one of the duties of a tramway to form a quick means of transit between the suburbs and the centre of a town. The lines are laid, therefore, in the majority of cases, radially or diagonally. These radial lines are then sometimes joined by circular routes, as shown in fig. 4. As far as possible the lines in the centre of the town should pass along different streets, so as to avoid too great a congestion of traffic in any one of them. In newer towns, where the streets run more or less either parallel or at right angles to one another, as in most of the large American cities, it is usually impossible to have radial and ring lines; the tramway lines are then laid parallel or at right angles to one another, the distance apart of the individual lines being determined by the density of the traffic (fig. 5).

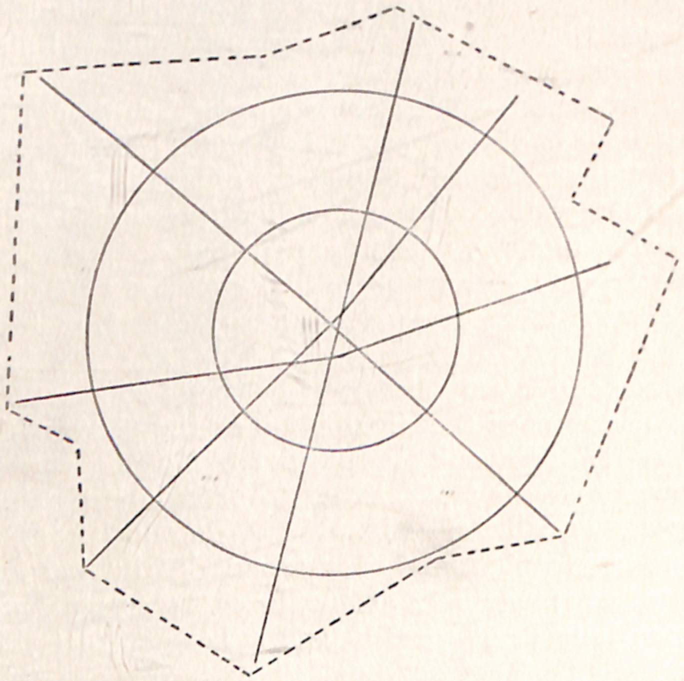


Fig. 4.—Diagonal and Radial Arrangement of Routes

Position of the Rails in the Street.—

1. *Single-track Lines.*—The portion of the street breadth required for the cars or the operation thereof, i.e. which includes the necessary free play, cannot be taken less than 8 feet. The *smallest breadth of roadway*, *b* (fig. 6), in which a single line of tramway can be laid down, therefore, amounts to 16 feet. Since the distance, *a*, from the centre of the track to the pavement kerb, on the grounds of safety, is not allowed by the Board of Trade to be less than 4 feet 10 inches (for a 4-feet-8½-inch gauge), and where possible should equal 5 feet, we thus see that the least value of *b* required is 17 feet. For the reasons given above it is evident that the actual size of gauge used does not influence this result to any great extent. In order that there may be sidings in such narrow streets the rails at these places would come very close to the kerb.

If the street is broad enough to allow of traffic on both sides of the tramway line, i.e. if the breadth of the street be 24 feet or over, the tramway track should always lie in the centre of the street. This has the disadvantage to passengers of requiring them to cross over the roadway to reach the cars, but it avoids the inconvenience which dwellers in the street on one side would have of being unable to have any vehicle standing in front of their houses, due to the tramway rails being there. A further advantage is that by laying the line in the middle of the street it is much easier to have both rails at the same level, which would be very difficult to do if the rails were laid at one side, and at the same time such an arrangement of line tends to regulate the traffic, since it divides it into the two directions (fig. 7).

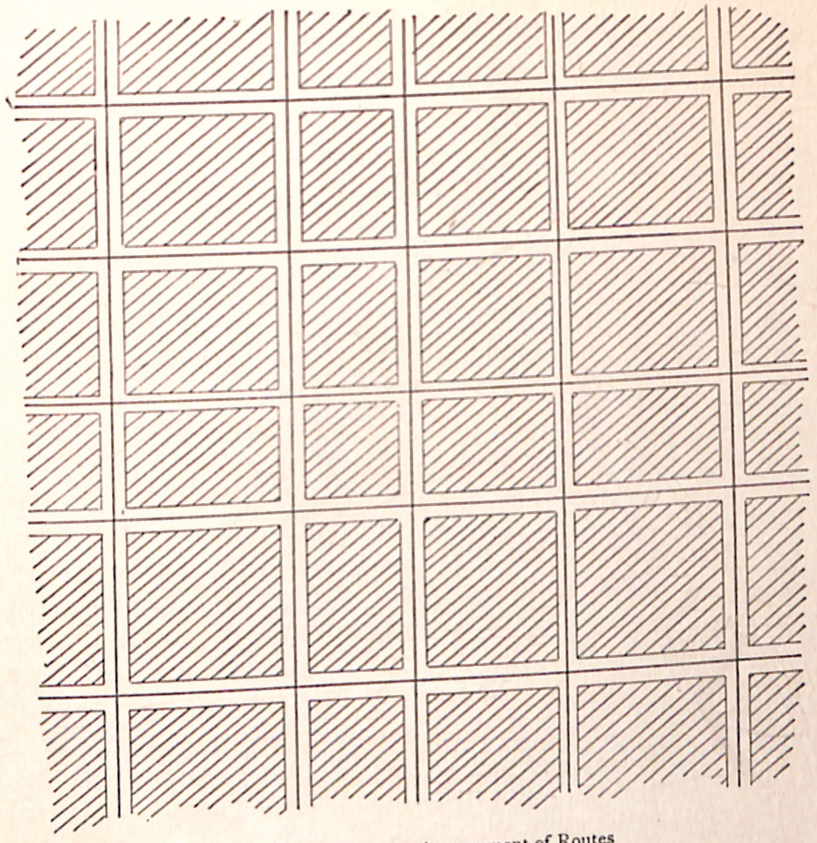


Fig. 5.—Rectangular Arrangement of Routes

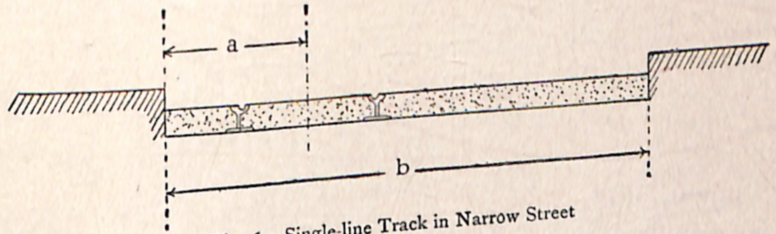


Fig. 6.—Single-line Track in Narrow Street

2. *Double-track Lines.*—A double-track line requires a roadway at least 32 feet wide. If such a breadth does not occur, and also if the two lines

cannot be laid so as to pass along parallel streets, then it is unavoidable to have the lines laid near the side of the street. With a street having buildings along one side only, such an arrangement has no special disadvantages; and in other cases the difficulty is partially overcome in various ways, e.g. by the laying of deviation sidings which, in cases of necessity, allow of the cars passing from one line to the other. In very narrow streets it is sometimes arranged that the cars, during definite hours, only utilize the line on one or the other side of the street. In this

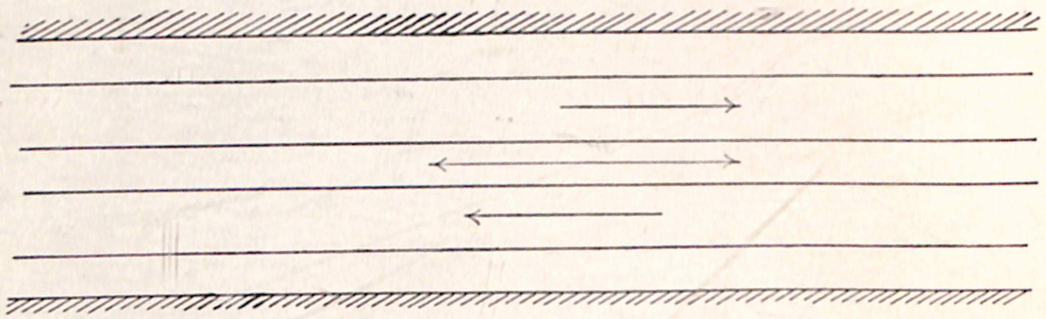


Fig. 7.—Single-line Track in Broad Street

case there is not really a double-line traffic at all, but only a single line, at one side or the other, with its accompanying disadvantages.

With an ordinary double track the distance apart of the two tracks should be at least 8 feet 6 inches, measured from the centre of one track to the centre of the other. At curves this distance must be considerably increased so as to prevent two cars touching when passing one another on the curve (see fig. 28). The usual distance between the tracks is 8 feet 8½ inches; this, as all other dimensions given above, refers, of course, to the standard gauge of 4 feet 8½ inches.

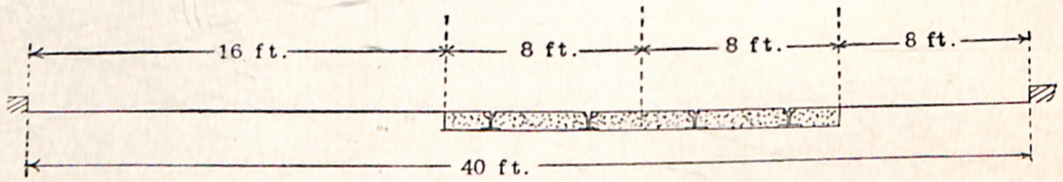


Fig. 8.—Suitable Arrangement of Lines for a 40-foot Street

Tramway Lines along Country Roads.—In laying the tramway along a country road the line may be placed at the side of the road, since in this case the disadvantages which occur in a built-up street are not present.

Layout of Broad Streets.—For streets with a roadway of more than 32 feet, in order to utilize this breadth in the most favourable manner the lines are so arranged that the whole roadway is divided into strips of about 8 feet in breadth each. With a breadth, for example, of 40 feet the lines are most suitably placed somewhat towards the one side, as shown in fig. 8. In a broad street divided into two portions by a promenade or bridle path the tramway lines are laid close along the promenade (fig. 9). In a few particular cases a special arrangement of street can be carried

out as shown in fig. 10, where the tramway lines are situated in the centre, then on each side comes a grass plot or strip of ground laid out with flowers or shrubs, &c., then comes the ordinary roadway, and finally the pavement. It is important to note that the more the ordinary traffic of

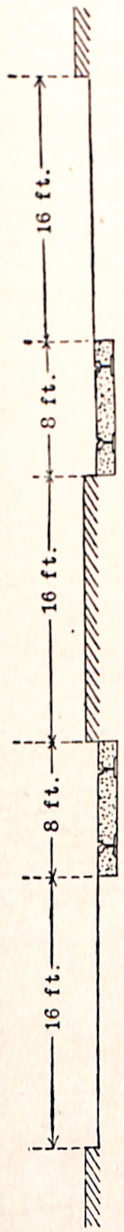


Fig. 9.—Arrangement of Broad Street with Promenade in Centre

Fig. 10.—Special Arrangement for Very Broad Street

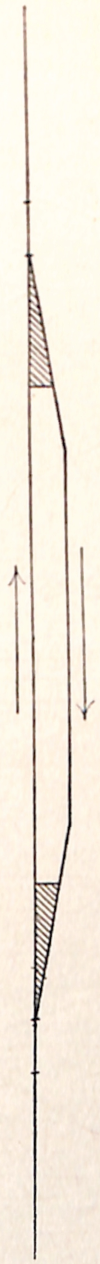


Fig. 11

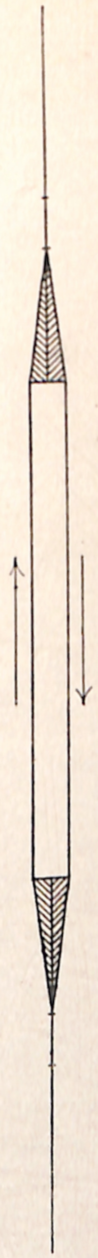


Fig. 12

Fig. 13

the street can be removed from the tramway lines, the higher, naturally, can the speed of the cars be allowed to be. The use of a single or double track depends, apart from the limits imposed by the width of the streets, upon the density of the traffic. With a closer service than eight or ten minutes a double track is necessary.

Sidings.—In order to allow of traffic in both directions on a single-track route, sidings must be inserted at certain points along it. The distance apart of these sidings depends upon the average speed of the cars and the "service", i.e. the interval of time at which the cars follow one another. If we indicate the service, or the time between the cars, by t minutes, and the average speed in miles per minute by v, then, since there can only be either one car or the other in the opposite direction,

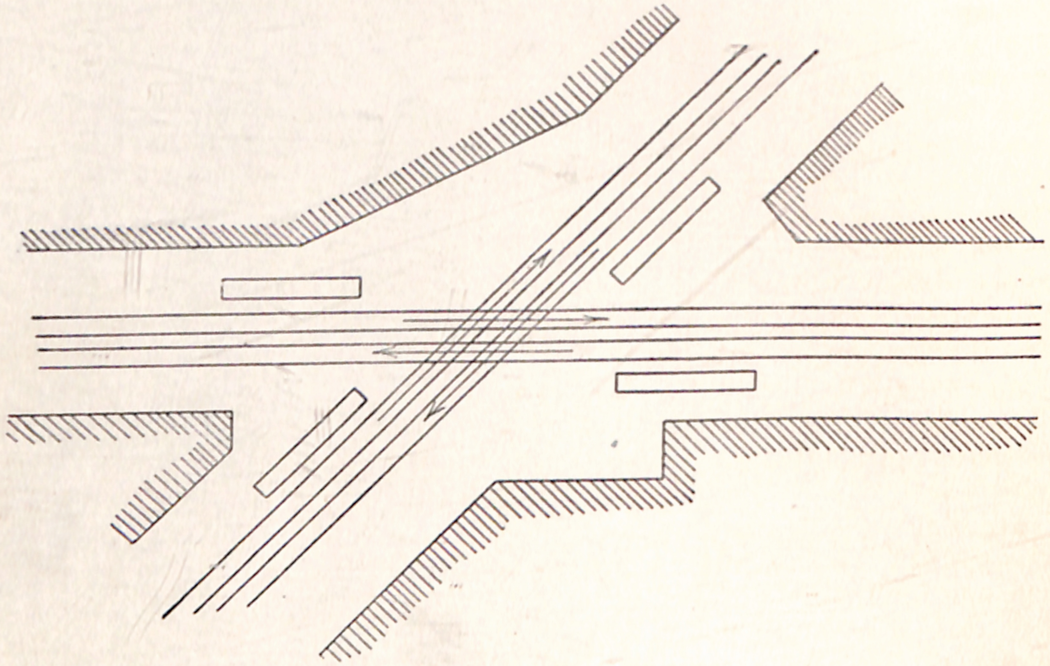


Fig. 14.—Busy Crossings showing "Islands

alternatively, on the stretch between two sidings at one and the same time we have the distance apart of the sidings:

$$d = \frac{t \cdot v}{2},$$

or, if V is the velocity in miles per hour, then $V = 60 \cdot v$, and

$$d\,(\text{miles}) = \frac{t\,(\text{minutes}) \cdot V\,(\text{miles per hour})}{120}.$$

Thus with a velocity of 10 miles per hour and an 8-minute service the distance apart of the sidings is

$$d = \frac{8 \cdot 10}{120} = \frac{2}{3}\,(\text{mile}) = 3520\,(\text{feet}).$$

The length of the sidings should be between 80 and 160 feet, and they will naturally be situated at a place where the width of the street allows it. Three forms of sidings are shown in figs. 11, 12, and 13. In figs. 11 and 12 the points are usually moved by hand, though in fig. 12 the points can be held in one position by a spring. Fig. 13 shows a siding where fixed tongues can be used.

Stopping-places.—In the case of single-track routes the stopping-places always occur at the sidings. And in the case of both single- and double-track routes the stopping-places occur at street crossings and at important centres of traffic. If two or more tramway lines cross one another at any point, then stopping-places are always situated just before the crossing, unless, due to some exceptional reason, this cannot be done.

In broad streets, and especially in busy thoroughfares, "islands" are placed at the stopping-places for the protection of the passengers who are waiting for or alighting from the cars (see fig. 14). At busy thoroughfares also a shelter is sometimes erected for the convenience of waiting passengers.

Termini.—If only single cars without trailers are used, and the traffic on the line is not heavy, then the termini of the lines are simple. For a single-track line it is sufficient if a short parallel piece of track is connected to the main track by a turn-out (see fig. 15). If a siding be constructed at a short distance from the end of the track, then this second line can be omitted. With a double-track line both tracks are carried to the end of the terminus, and a cross-over is placed at a distance of from 150 to 200 feet from the terminus (see fig. 16).

Fig. 15.—Terminus for Single-track Line

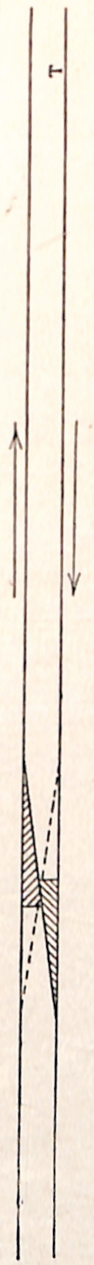


Fig. 16.—Terminus for Double-track Line

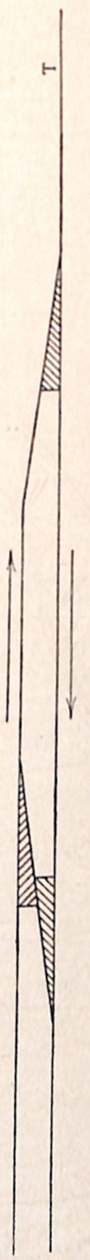


Fig. 17.—Double-track-line Terminus for Cars with Trailers

Fig. 18.—Double-track-line Terminus with Six Turn-outs

If trailers are used, then such a simple arrangement can no longer be adopted. For a single-track line a siding is required, as above mentioned, and for a double-track line three turn-outs or points will require to be inserted, as shown in fig. 17. In most cases a cross-over is added near the terminus, the rails being both carried to the end, as shown in fig. 18.

These arrangements are made so as to allow of the trailer being shifted to the back of the car for the return journey.

All kinds of shunting can be avoided if a loop can be constructed at the terminus (see fig. 19). This arrangement is much used in America. These loops are formed where an exceptional width of the street occurs, or in a square, and often encircle a block of houses, as shown in fig. 20.

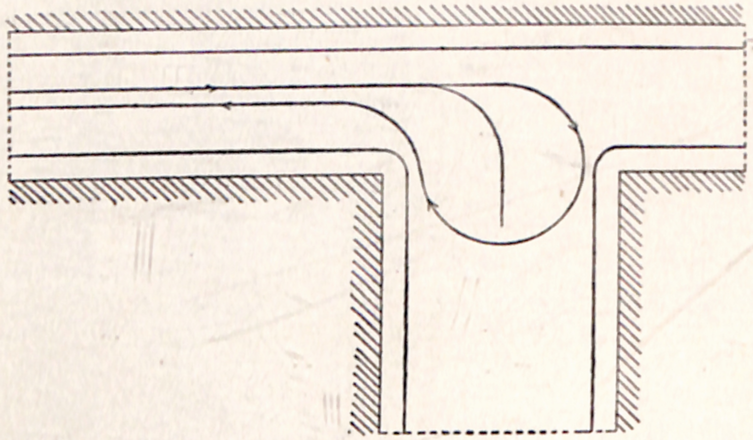


Fig. 19.—Loop Terminus

Points and Crossings.—The crossings of lines, branchings, and junctions occur very frequently in a tramway network. These require special constructional work which will be considered under The Permanent Way. Where the traffic is exceptionally heavy, as, for example, in New York, it has been decided to carry the tramway down underneath these parts. The cost of such an arrangement would only be warranted in a few such exceptional cases.

Gradients.—The maximum gradients with horse traction were about 1 in 20, or with trace horses 1 in 15. With electric traction, however, the limit depends, not on the tractive effort required, but on the limiting value of the adhesion between the rails and the car wheels. In foggy damp weather, when the wheels are apt to slip, this adhesion is increased somewhat by sprinkling sand on the rails. For cars without trailers inclines of 1 in 12 are often dealt with, and in some cases gradients of 1 in 8, or even 1 in 7, for short distances, are to be found. It is only with cable cars, however, that inclines such as 1 in 5 can be overcome.

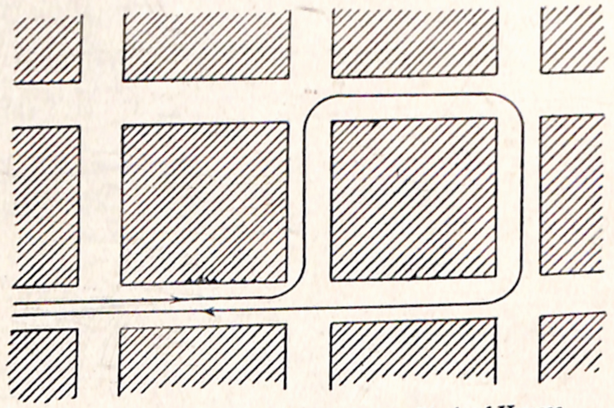


Fig. 20.—Terminus Loop carried round Block of Houses

Radius of Curves.—The necessity of passing from a narrow street into another at right angles to it often compels the tramway lines to have very sharp curves. The least permissible radius of curvature depends upon the gauge, the diameter of the car wheels, the depth of the wheel flanges, and to a very great extent upon the distance apart of the car axles. From

purely theoretical principles the least permissible radius could be calculated from the above data on the assumption of a perfectly rigid structure, but this would only give an approximate figure, since in practice a certain amount of free motion is always allowed. As a rule, 45 feet radius for the narrow gauge, and from 50 to 55 feet radius for the standard gauge, may be considered as the smallest that should be taken. In one or two isolated cases, however, even with the standard gauge, curves of 40 feet radius are to be met with.

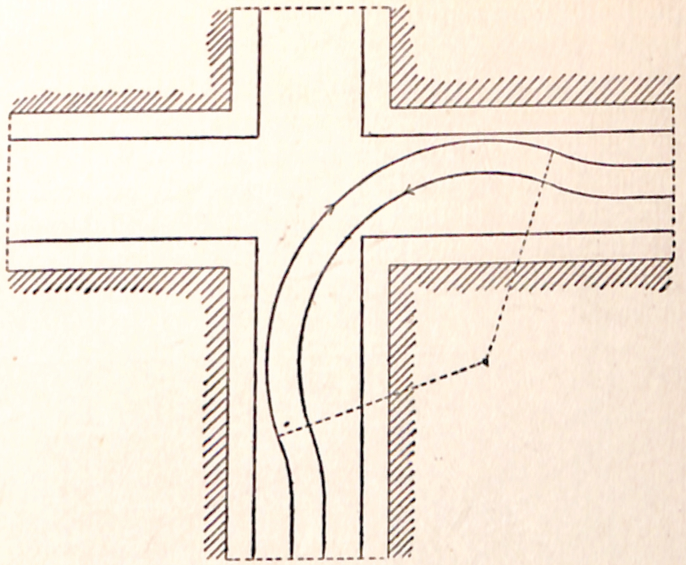


Fig. 21.—Insertion of a Double Curve

In order to prevent such extremely sharp curves, such an arrangement as shown in fig. 21 is sometimes made use of, where, as is seen, the line is made to take a double curvature.

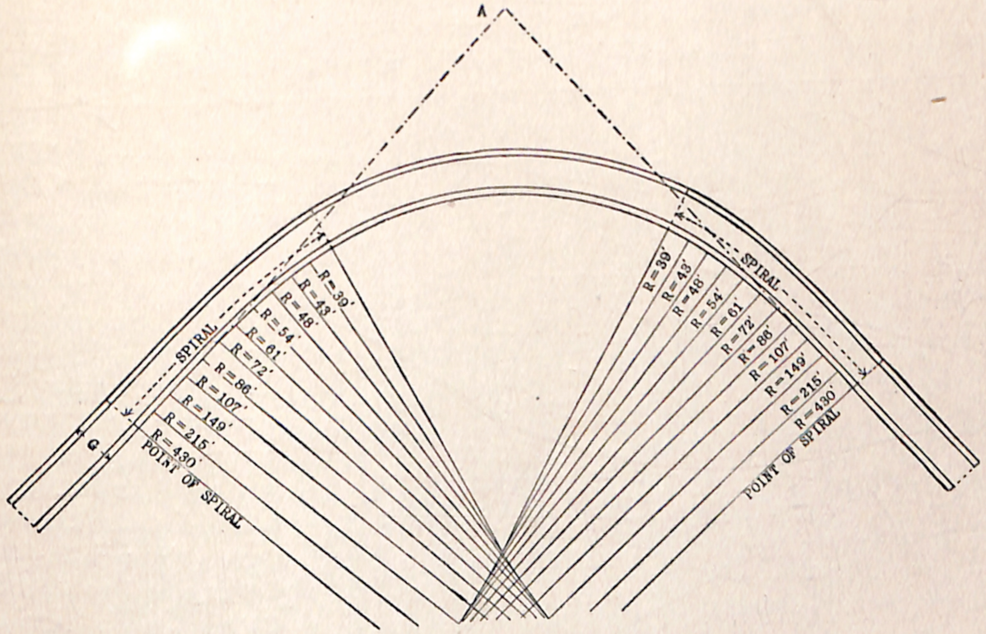


Fig. 22.—Special Spiral of Loraine Steel Company

Transition Curves.—In order to prevent the sudden shock to the cars as they enter sharp curves, as well as to reduce the wear on the rails at the entrance points, a transition portion is usually formed of such a shape as to gradually increase the curvature from zero to the maximum required. The force on the rails which causes the cars to take the curves will thus increase gradually from zero to a corresponding maximum.

Spiralized Easement Curve.—There is, first of all, the spiralized form of easement curve shown in fig. 22. This particular form has been chosen by the Loraine Steel Company so as to give a gradual increase of curvature with the shortest desirable length of spiral. In order that the same "points" may be used for all curves, the rate of change of curvature is in most cases made the same for all, the spiral being carried farther round for the sharper curves. The details of the most frequently used of these spirals are given in the following table. Note that the figures refer to the inner rail.

No.	Radius.	Added Angle.	Total Angle.	Total Arc.	Offset.		Projection Length.	
	Feet.			Feet.	Feet.	Inches.	Feet.	Inches.
1	429.7184	0° 20′	0° 20′	2.5000	0.0074	$0\frac{3}{32}$	2.5000	6
2	214.8592	0° 40′	1° 00′	5.0000	0.0363	$0\frac{7}{16}$	4.9998	0
3	143.2394	1° 00′	2° 00′	7.5000	0.1018	$1\frac{7}{32}$	7.4990	6
4	107.4296	1° 20′	3° 20′	10.0000	0.2180	$2\frac{5}{8}$	9.9962	$11\frac{31}{32}$
5	85.9437	1° 40′	5° 00′	12.5000	0.3999	$4\frac{13}{16}$	12.4895	$5\frac{7}{9}$
6	71.6197	2° 00′	7° 00′	15.0000	0.6610	$7\frac{15}{16}$	14.9756	$11\frac{11}{16}$
7	61.3883	2° 20′	9° 20′	17.5000	1.0160	$0\frac{3}{16}$	17.4501	$5\frac{3}{8}$
8	53.7148	2° 40′	12° 00′	20.0000	1.4794	$5\frac{3}{4}$	19.9063	$10\frac{7}{8}$
9	47.7464	3° 00′	15° 00′	22.5000	2.0629	$0\frac{3}{4}$	22.3373	$4\frac{1}{16}$
10	42.9718	3° 20′	18° 20′	25.0000	2.7799	$9\frac{5}{8}$	24.7319	$8\frac{13}{16}$
11	39.0653	3° 40′	22° 00′	27.5000	3.6416	$7\frac{11}{16}$	27.0783	$0\frac{15}{16}$

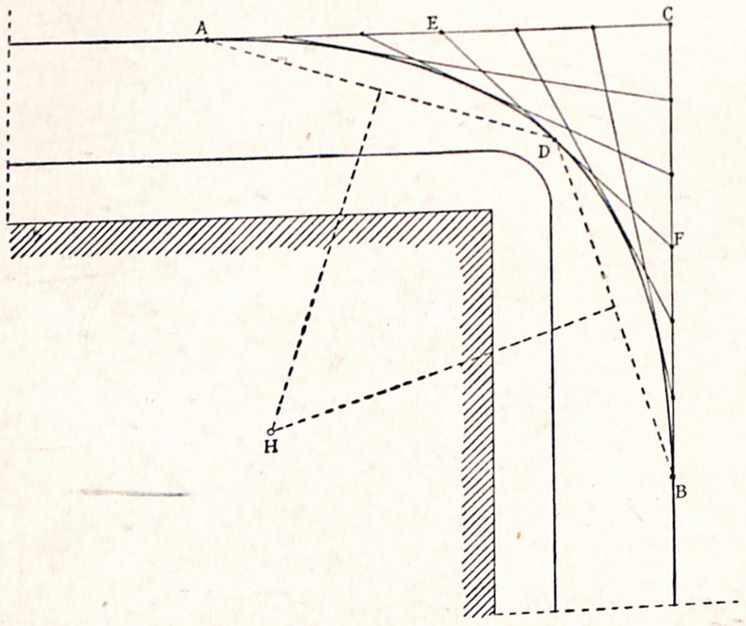


Fig. 23.—Parabolic Curve

Parabolic Curve.—Another method of laying out a curve is shown in fig. 23. The lines A C and B C are those to be connected by a curve passing through D, a point as near the kerb as is permissible. Pegs are put at D and C, and E F laid out so that it passes through D, and C E is equal to C F, or E F is perpendicular to C D. Then A E is taken equal to E C, and B F to F C. A E, E C, B F, and F C are

now divided into an equal number of portions, say three, as shown in fig. 23, and the construction lines are drawn as shown. The curve is drawn which has all these construction lines as tangents to it.

It is best to construct this curve on the ground, full size, putting stakes in the ground at the various points A, B, C, &c., and using tapes or cords to mark out the construction lines. The distance C E should never be taken less than 24 feet. It will be readily seen that this is one method of constructing a parabolic curve.

The following table gives the various particulars of curves for different values of C E:—

	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
When CE is	24	27	30	33	36	39	42
Radius at A is	96	106	120	132	144	156	168
Radius at D is	34	38	43	47	51	55	59
Single radius passing through D ...	41	45	51	56	61	66	72

Cubical Parabola.—In Germany the curves of electric tramways which have a radius less than 100 metres have their entrance portion made parabolic. The formula used is as follows:—

$$y = \frac{x^3}{6RL},$$

R being the radius of the curve in metres, and L the length of the entrance portion. By substituting the values of R and L we get for each value of the abscissæ x_1, x_2, x_3, &c., a corresponding value of the ordinates y_1, y_2, y_3, &c., which determines the shape of the entrance curve.

The length of the entrance curve is, as a rule, made equal to the length

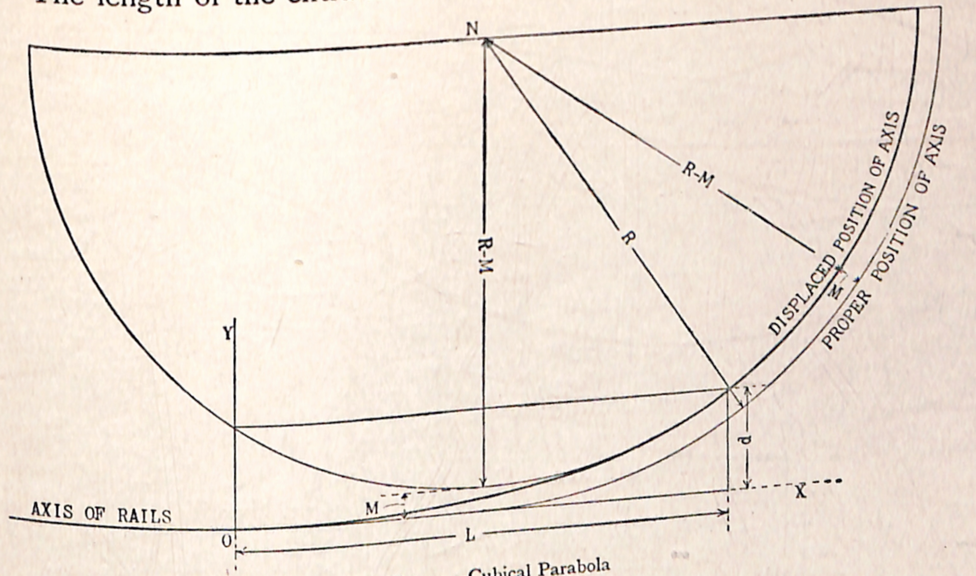


Fig. 24.—Cubical Parabola

of the gradient due to the superelevation (see below), or L usually equals $100 . h$. (h = superelevation in millimetres.) $\frac{L}{2}$ is laid before the curve proper is reached, and $\frac{L}{2}$ is laid in the curve itself (see fig. 24).

In order to get the correct junction it is then necessary to displace the axis of the rails by a distance M, where $M = \frac{d}{4}$. The distance M amounts, as a rule, to not more than 0.10 metre.

Between two curves of opposite curvature a short transition straight portion is inserted, the length of which should be at least equal to the distance between the car axles.

Speed on Curves.—The outer rail on curves for a tramway cannot, as a rule, be raised above the level of the inner, as is done on railroads, since the smooth surface of the street must not be interfered with; hence the cars, for the sake of safety, should not be allowed to go round the curves at a high speed. Care must be taken, of course, never to allow the outer rail to be lower than the inner, due to any unevenness of the street level.

The speed at which the effect of the centrifugal force would be sufficient to tilt the car can be calculated as follows:—

Let F_c = centrifugal force (pounds).
W = weight of car in tons.
w = " " pounds.
V = speed of car in miles per hour.
v = " " feet per second.
g = acceleration due to gravity 32.2 feet per sec. per sec.
G = gauge in feet.
h = height of centre of gravity of car in feet.

Then from fig. 25, maximum F_c, i.e. one just sufficient to tilt the car, is such that

$$F_c . h = w . \frac{G}{2}.$$

But $F_c = \frac{w . v^2}{g . R}$, where R = radius of curve in feet,

$$\text{therefore maximum } v^2 = \frac{w . G . g . R}{w . h . 2} = \frac{32.2\, G . R}{2 . h},$$

$$\text{or maximum } v = \sqrt{16.1\, G . \frac{R}{h}};$$

$$\text{and as } V = \frac{v}{1.47},$$

$$\text{maximum } V = 2.73\sqrt{G . \frac{R}{h}};$$

$$\text{and as for standard gauge } G = 4.7,$$

$$\text{maximum } V = 5.93\sqrt{\frac{R}{h}}.$$

If, as in Glasgow, the minimum value of R = 30 feet, and $h = 4\frac{2}{3}$ feet,

$$\text{maximum } V = 5.93\sqrt{\frac{90}{14}} = 15.03 \text{ miles per hour.}$$

Of course it would not do to risk running anywhere near this speed in practice; indeed, no more than half this value, or $7\frac{1}{2}$ miles per hour, should be permitted on such a curve.

Superelevation of the Outer Rail.—Though superelevation of the outer rail on a curve is seldom permitted in any part of a town tramway, much less on a busy street, a certain amount of superelevation is sometimes obtained by using for the outer rail a stretch of rail with a shallow groove. The advantage of such a rail is, however, very questionable. Not

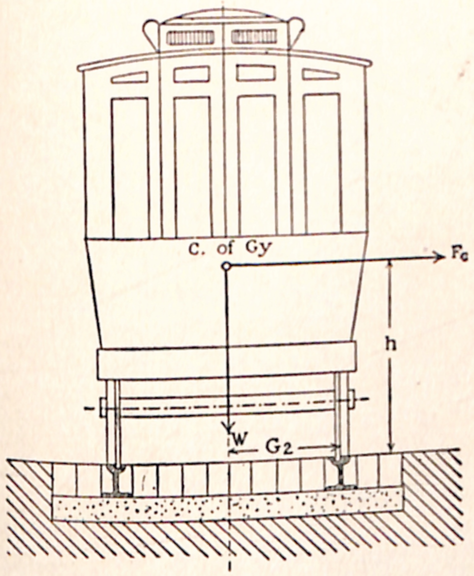


Fig. 25.—Effect of Centrifugal Force

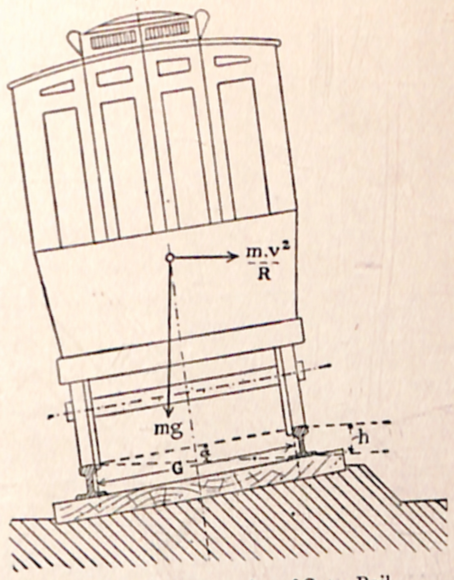


Fig. 26.—Superelevation of Outer Rail

only does it bring in a special form of rail for certain parts, which makes it difficult to replace, but also the insertion of such requires a transition rail, and also special joints at the beginning and end of all curves.

When a tramway is laid along a special track, especially in the country, where the speeds are high and the rails are often of the bull-headed type, superelevation should be used on all curves less than 100 feet in radius. To determine the amount of superelevation for a given speed, to counterbalance the effect of the centrifugal force, consider fig. 26.

Then where e = the superelevation,
and α = the inclination of the track to the horizontal (radians),
we have e (feet) = $G . \tan \alpha$,

$$\text{therefore } e \text{ (inches)} = 12 . G . \tan \alpha = 12 . G . \frac{m . v^2}{R . m . g},$$

$$= 12 . \frac{G . v^2}{R . g},$$

$$\text{but } v = \frac{22}{15} . V, \text{ and } g = 32.2;$$

$$\text{therefore } e = \frac{12 \times 428}{225 \times 32.2} . \frac{G . V}{R} = \frac{1}{1.25} . \frac{G . V}{R}.$$

Take now the maximum value of V as 8 miles per hour, as above; then

$$e = \frac{64}{1.25} \cdot \frac{G}{R} = 51.2 \frac{G}{R}.$$

From this we get the following table for the superelevation required:—

Radius of Curve R.	Standard Gauge 4′ 8½″.	Narrow Gauge 3′ 6″.
Feet.	Inches.	Inches.
50	4.81	3.58
100	2.41	1.79
150	1.60	1.19
200	1.20	0.90
250	0.96	0.72
300	0.80	0.60
350	0.69	0.51
400	0.60	0.45
450	0.53	0.40
500	0.48	0.36

Since the superelevation e must occur at the curve, it is important to note that the rate at which it rises (which also, to a certain extent, deter-

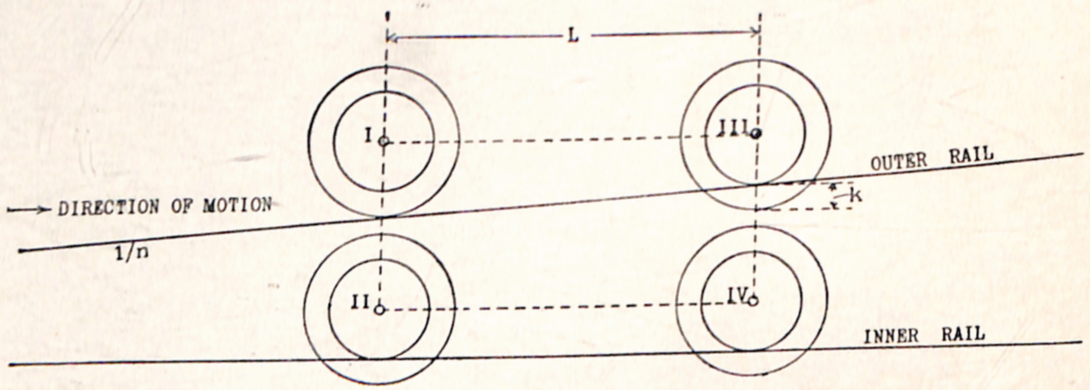


Fig. 27.—Slope of Transition Ramp

mines the length of the transition curve) is determined by the distance apart of the car axles and the depth of the wheel flanges.

Fig. 27 shows, on the assumption of a rigid structure, that the front pair of wheels must rest on their treads, the one on the rising rail and the other on the inner one; the outer wheel of the back pair cannot, however, do so, but is raised from the rail to a certain extent. The flange must not, however, be raised so as to clear the top of the rail, otherwise the wheel would be apt to slide off the rail altogether; hence the gradient of the transition ramp must not exceed $\frac{1}{n}$, where $\frac{1}{n} = \frac{k}{L}$; where L is the distance between the car axles, and k is the depth of the wheel flanges.

In Glasgow, $k = \frac{3}{8}$ inch, and L (minimum) = 6′ = 72″, hence

$\frac{1}{n} = \frac{3}{576} = \frac{1}{192}$, so that the length of the superelevation ramp is
$L_1 = 192 . e.$

Widening of the Groove and Alteration of the Gauge.—The amount of widening of the groove at curves depends on the distance apart of the car axles, the diameter of the car wheels, and the depth of the flanges. It is made to prevent the flanges of the car wheels from grinding against the edges of the rail grooves on the curve; the lip or guard is usually made thicker to allow for the extra wear (see figs. 36 and 37).

While the wheels of the standard railway rolling-stock have a cone-shaped rim of from 5 to 6 inches broad, the wheels of the rolling-stock for electric tramways have a flat rim with a breadth of about 3 inches; on this account the danger due to slipping off the rails, due to a great increase in the width of the gauge, is far greater in the latter case than with railways. For this reason it is recommended that a less increase of width on curves should be chosen with electric tramways. Again, since the distance apart of the wheels with tramways is smaller than with railway rolling-stock, this causes a still greater reduction in the widening of the gauge, as also does the less depth of the flanges; indeed, these latter factors act to such an extent that a suitable gauge is sometimes *smaller than* that on the straight, that is, there is a *decrease* in the gauge at curves.

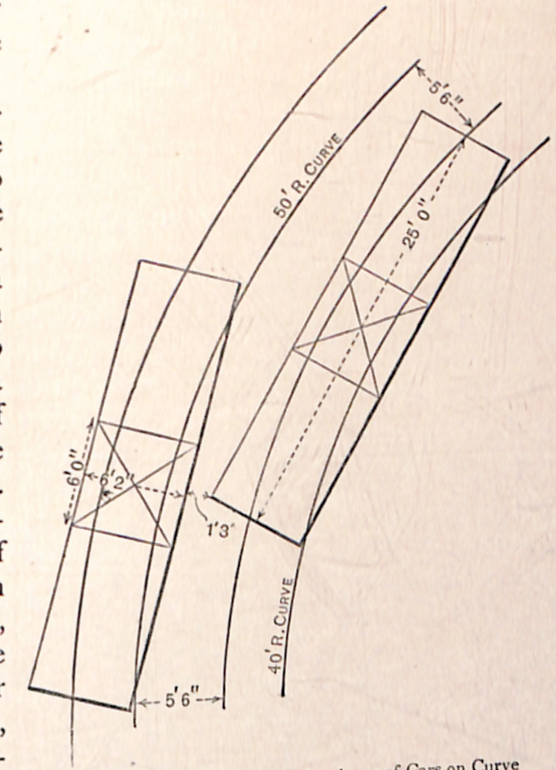


Fig. 28.—Plan showing the Overhang of Cars on Curve

Again, in a double-track line the distance between the centre lines of the two tracks is increased at curves, so as to prevent two cars going in opposite directions round the curve from touching one another, due to the overhang beyond the wheel base (see fig. 28).

CHAPTER III

THE PERMANENT WAY

Forms of Cross-section of the Rails—Historical.—The groove in the first tramway rails used by Loubat, in New York, was very wide and deep, and, as this was found to be dangerous to other street vehicles, since many of them had narrow tires, this form was discontinued, and a step rail was designed and used first in Philadelphia in 1885 (see fig. 29). This form of rail was tried in this country, but, due to the large slippery surface which it presented, it was abandoned for a flat-groove rail.

The step rail is more easily kept clean, but as the flat-groove rail proved less of a nuisance to the ordinary vehicular traffic, it has become the standard type, not only in this country, but also in the large American cities. To stiffen the rail, flanges were added to the sides, which also helped to prevent any side play, the rail being fixed to the longitudinal timbers as shown in fig. 30. The rails were next supported on cast-iron chairs, the section being altered to that shown in fig. 31, which was fixed into a continuous cast-iron chair.

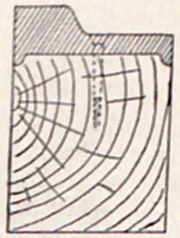


Fig. 29

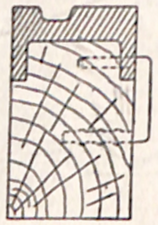


Fig. 30

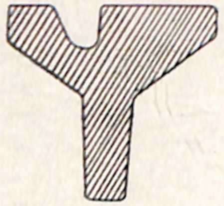


Fig. 31

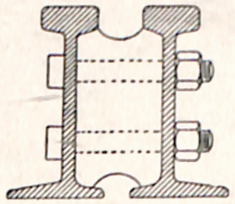


Fig. 32

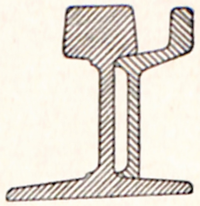


Fig. 33

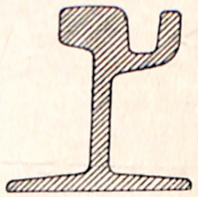


Fig. 34

The introduction of mechanical traction with heavier loads required a more solid construction, and the girder type of rail was introduced about 1880. This is gradually superseding the built-up form of Haarmann. Various forms of rail sections are shown in figs. 32, 33, and 34.

Weight and Size of Rails.—The weight and dimensions of the rails to be used in any special case are determined by the necessary strength and resistance to wear required, due allowance being made for the method of laying and supporting the rails in the body of the street.

The strength and stiffness of the rails used have gradually increased with the development of tramway working. While with horse tramways the pressure on each wheel was only about ½ or 1 ton, since the introduction of electric traction the amounts dealt with have increased, till now they amount to more than 3 tons. At the same time the number of vehicles which pass over a given stretch of rail within a given period has so much increased that in some parts where the traffic is heavy this reaches an extremely high figure.

A considerable height of rail is usually chosen, since the rail is laid, as a rule, direct on the road foundation, without sleepers. On this account the required stiffness can only be obtained by means of a corresponding increase in the height of the rail. For this reason also a broad flat base is desirable, since in spite of the absence of the cross sleepers the pressure on the foot of the rail is exceptionally great.

The groove is chosen of such a width that the flanges of the car wheels have sufficient play and do not catch on the sides. The depth of the groove must be sufficient to prevent the wheels riding on the top of the flanges in the bottom of the groove and not on the tread, as they should. The usual breadth of the groove is from 1 to 1½ inches.

Standard Sections.—The number of cross-sections which have been used up to the present is very great. In the interests of tramway management, as well as of rolling-mills, the British Engineering Standards Committee have chosen certain definite sections as standards. These are all of the solid girder type. There are five sections for straight tracks, with corresponding sections for curved tracks. The fish-plate sections are similar for both sets of tracks. Their general particulars are given in the following table:—

"B.S." Section.	Rails.			Fish-plates.	
	Height.	Width of Base.	Normal Weight Per Lineal Yard.	Weight of Inner.	Weight of Outer.
Number.	Inches.	Inches.	Lbs.	Lbs.	Lbs.
1, 1c	6½	6½	90, 96	22½	27½
2, 2c	6½	7	95, 101	22½	27
3, 3c	6½	7	100, 106	22½	26½
4, 4c	7	7	105, 111	26	30½
5, 5c	7	7	110, 116	26	30½

The affix *c* to the "B.S." number denotes that the rail is for use on curves, the difference between the straight track and curve rails being that the groove is ⅛ inch wider and the guard or lip thicker and higher in the latter. All the sections have heads of identical profile as regards the groove and the angle of the rail table. This profile gives a groove 1⅛ inches wide by 1¼ inches deep, measured from the highest point of the table, which has a slope of 1 in 21. The guard or lip is ⅛ inch below the highest point of the table. In the curve rails the groove is 1¼ inches wide and the lip is brought up level with the table. The only difference in the profile of tires for running on the various sections is in the width of the tread to suit the varying widths of rail-table, i.e. from 1⅞ inches in Nos. 1 and 1c to 2¼ inches in Nos. 5 and 5c (fig. 35).

The normal length of the rails is about 45 feet, but 35- and 60-foot lengths are also used, 35 feet being the length usually used on curves.

Chemical Composition.—The committee have likewise drawn up a standard specification for the manufacture of tramway rails, prescribing

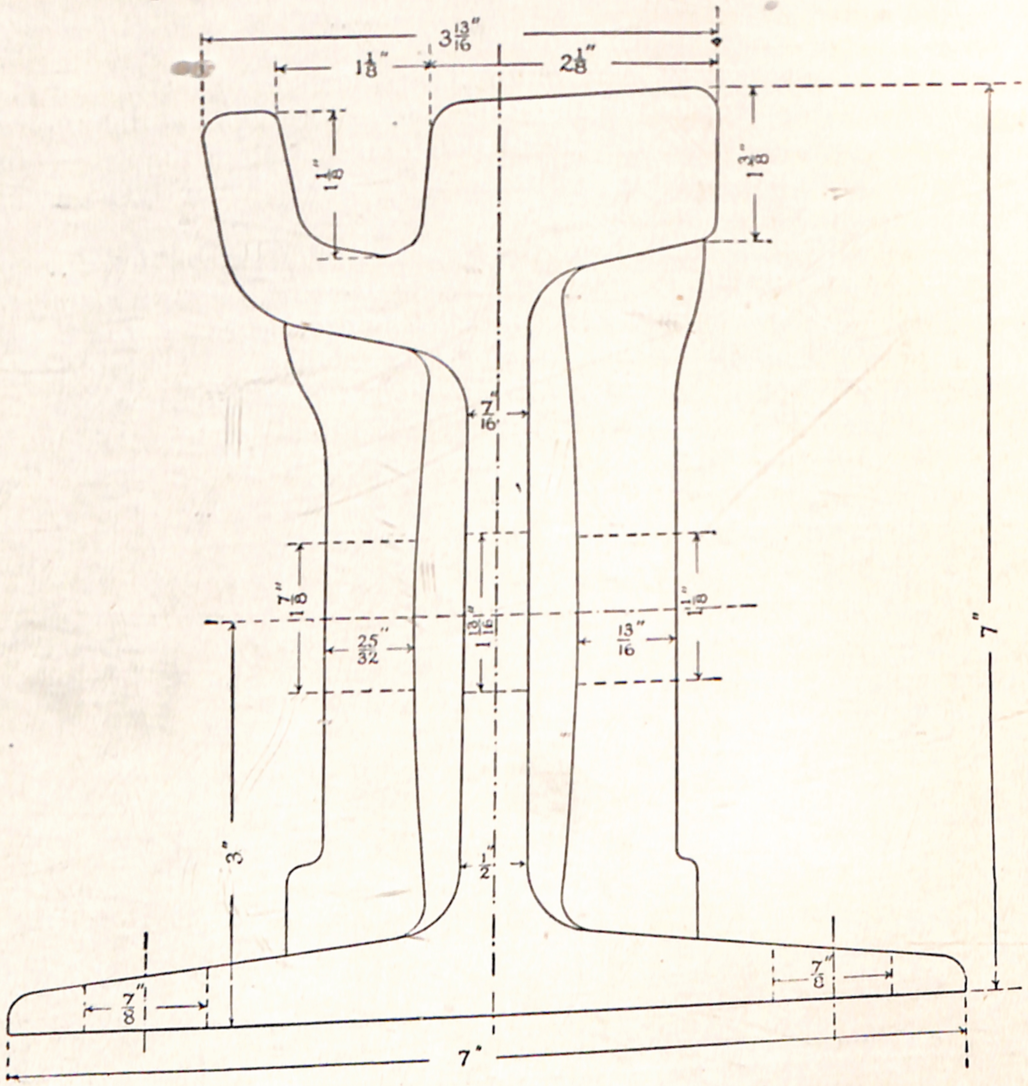


Fig. 35.—British Standard Tramway Rail, Section No. 4, 105 lbs. per yard

the chemical constituents, physical tests, &c. The principal provisions are briefly as follows:—

Steel to conform to following limits:—

Carbon	from 0.40 to 0.55 per cent.	
Manganese	„ 0.70 „ 1.00	„
Silicon	maximum 0.10	„
Phosphorus	„ 0.08	„
Sulphur	„ 0.08	„

The increased loads on the rails, as well as trouble due to "corrigations", has caused engineers in special cases to introduce steel of a very

high tensile strength, such as nickel steel or manganese steel, and electric power is being used for dealing with such extremely hard materials, as well as, as a motive power for handling the same.

Physical Tests.—The physical tests are threefold: The Impact test, the Tensile test, and Bending.

First, Impact Test.—A 5-foot test-piece, head uppermost, is supported horizontally on solid iron bearings 3 feet 6 inches apart in the clear, and a tup or ball having 9 inches radius face, and weighing not less than 1 ton, is dropped on to it, midway between the bearings, from a height of 15 feet

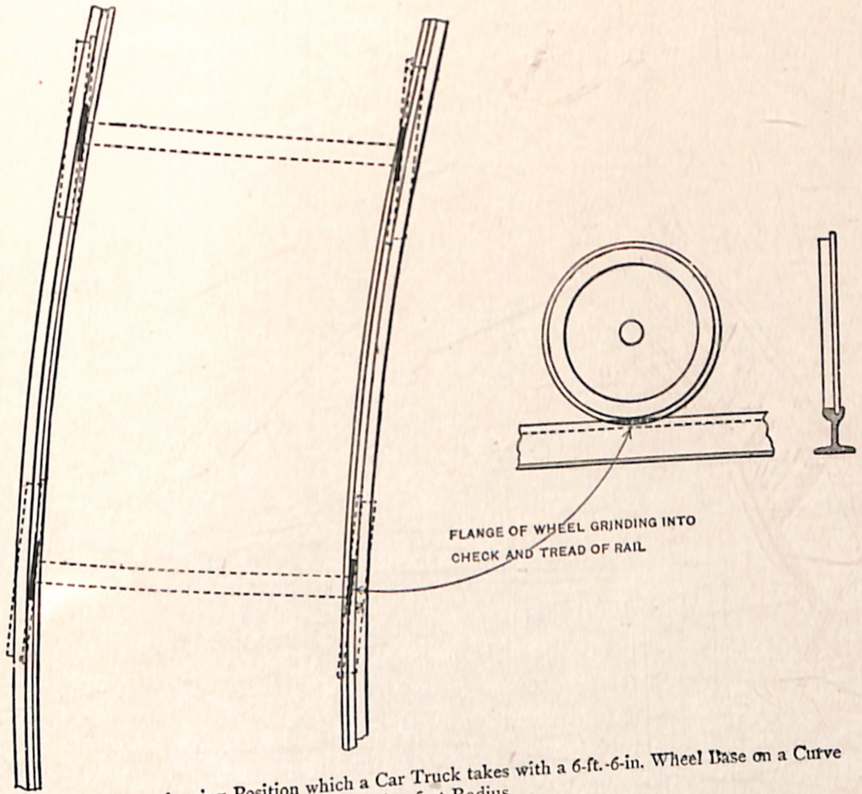


Fig. 36.—Plan showing Position which a Car Truck takes with a 6-ft.-6-in. Wheel Base on a Curve of 40 feet Radius

for rails under 100 lbs. per yard, and of 18 feet for rails of 100 lbs. and over per yard. The rail should not fracture under such a test.

Second, Tensile Test.—From each 100 tons of rails a test-piece is cut from a selected rail. This piece is machined to a sectional area of ½ square inch and a length of 2 inches between test-gauge points. The ultimate tensile strength should be not less than 40 tons per square inch, with an elongation of not less than 12 per cent on a length of 2 inches.

Third, Bending.—From each 100 tons of rails a selected rail is tested by bending sideways to a curve of 30 feet radius, and it should show no signs of cracking.

Sections at Curves.—In passing round curves the wheels lie in an oblique position to the rail axes, whence, if there is not sufficient room, a rubbing of the flanges takes place against the sides of the grooves (see fig. 36). But besides, on curves a greater wear is noticeable on the guard, since the cars can only pass round by the flanges being forced against the sides of the groove. Again, since the length of the outer rail is longer than the inner, there must occur a certain amount of skidding and grinding between the wheels and the rails. Hence at curves the grooves are widened and the guard of the rail is strengthened.

The strength of the guard rail in the Haarmann type is of less importance, since the guard rail can, if necessary, be replaced without the main portion being taken up. This, of course, cannot be done with the girder rail of the solid type. Fig. 37 shows the cross-sections of rails used at curves.

Methods of Supporting and Fixing the Rails.—As already mentioned, longitudinal timbers or sleepers originally served as a bedding for

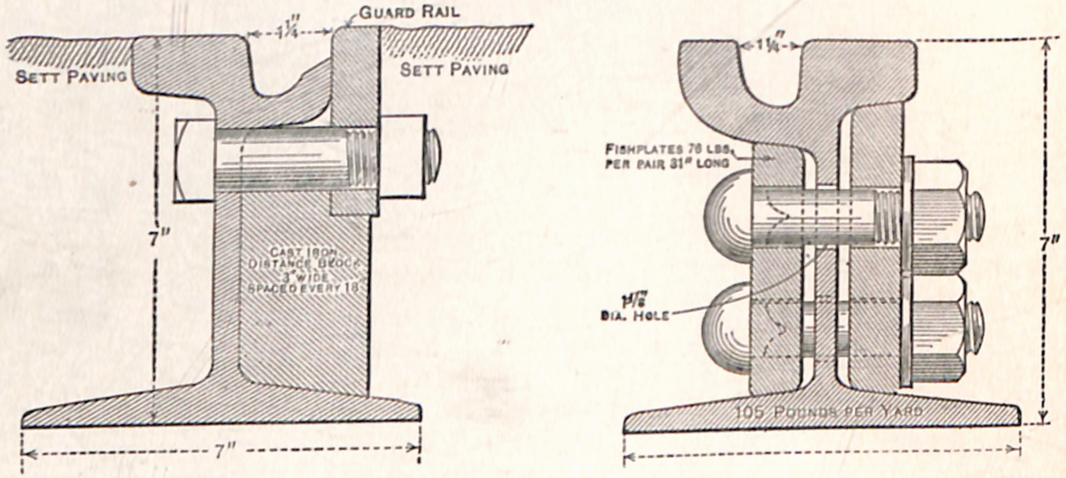


Fig. 37.—Rail Sections adapted for Short Curves

the rails, even longitudinal sleepers of granite were used, and, later, sleepers of cast iron were adopted for this purpose. With the introduction of the deep girder rail such supports were completely done away with, and the rail was laid direct on the ground foundation. The principal disadvantage of the wooden longitudinal sleepers lay in their small durability, and the necessity, when renewing them, of having to remove two lengths of rail, as the sleeper joints were placed at the centre of the rail lengths.

The introduction of cross sleepers ensured a satisfactory distribution of pressure, and hence was the best way of keeping a uniform height of rail. It is necessary, however, when changing them, that the whole of the street paving between the rails, and a certain distance on both sides of them, be torn up. This makes their use with a sunken rail, i.e. a rail embedded in the road, a costly piece of work. Hence, in Europe, their application to tramway rails is limited to those cases where, in consequence of the yielding nature of the subsoil, these disadvantages must be accepted in the interest of a safe rail support.

In this case a special high rail profile should be chosen, so that the lower edge of the stone setts can lie over the sleepers. In modern times cast-iron sleepers and sleepers of reinforced concrete have been used; longitudinal sleepers of cast iron have also been tried.

Rail Joints.—The rail joints are always the weakest points in the permanent way, and have caused the engineer to be continually considering new methods of constructing them. According as allowance is made for the expansion of the rails due to variations of temperature, or not, we have two principal forms of rail joints. First, rail joints with allowance for expansion of the rails, i.e. fish-plated joints; second, welded joints.

Fish-plated Joints.—This form of connecting the rails together is the

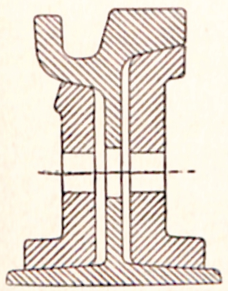


Fig. 38

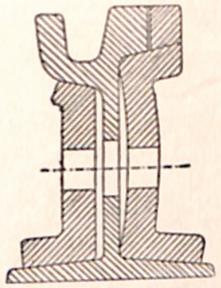


Fig. 39

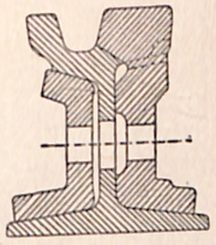


Fig. 40

older, and, up till a short time ago, almost the only one used. It is founded on the fundamental law, taken from railway construction, that in order to avoid the twisting of the rails out of their places it is necessary to allow a free space at the joints between the ends of the rails, which is great enough to permit the expansion of the rails, due to heat, to take place.

With the girder form of rail, side fish-plates are used, similar to those in railway construction. Fig. 38 shows a joint with side fish-plates for a grooved rail. This arrangement is that most used. The fish-plates are usually 2 feet long, and should make a good fit between the head and the bottom flange of the rail. For great wheel pressures and heavy traffic, however, this form of rail joint is too weak, since it offers very little resistance to deflection of the rails at the ends. In order to obtain the necessary strengthening, various arrangements have been adopted. Thus, in fig. 39 the outer fish-plate is carried right up as high as the tread of the rail, and the top of the rail is slotted out to receive it; thus the wheels pass over the gap without a jolt. The complete substitution of the tread of the rail by the fish-plate occurs in the joint shown in fig. 40, where the tread of the rail is completely cut away, and is replaced by a corresponding fish-plate. The advantage of this form of connection is that the joint can be easily renewed without removing the rails out of the setts. From another

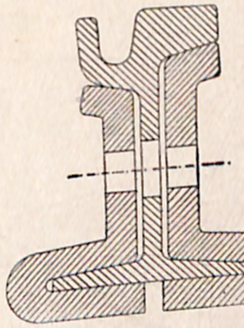


Fig. 41

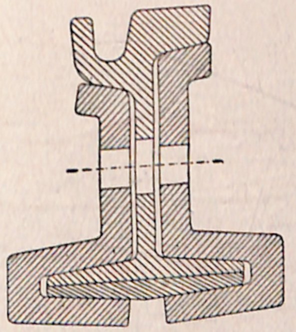


Fig. 42

point of view there are the numerous forms of rail connection which endeavour to prevent deflection of the ends of the rails by supporting the foot of the rail. Examples of this form of connection with a foot fish-plate are shown in figs. 41 and 42; the second, with a wedge-piece inserted,

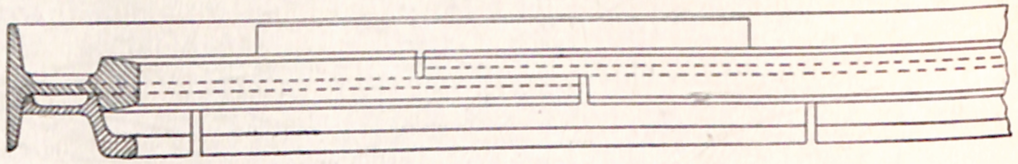


Fig. 43.—Arrangement of Joint for a Haarmann Rail

due to the difficulty in the first case of getting a satisfactory contact with the bottom of the rail. Fig. 43 shows the arrangement of the joints for a Haarmann rail.

Anchor Joints.—This is a form of joint used to a great extent in this country. It consists merely of a girder or inverted piece of rail about 2 feet long, bolted or riveted (preferably the latter) to the under side of the

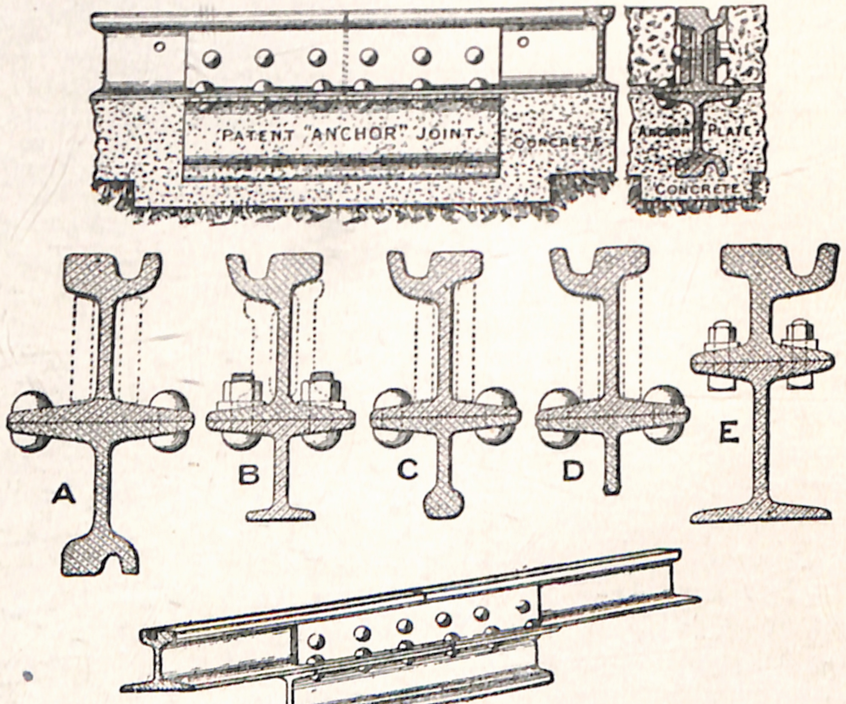


Fig. 44.—Sections of Anchor-joints

rail under the joint, and sometimes at intermediate points of the rail. The concrete, which is bedded round the anchor-plate, keeps the joints tight, and prevents vibration, which usually loosens the fish-plates and copper bonds. It has been found a great advantage, also, to fix an anchor-plate in the centre of each rail, in order to prevent vibration of the rail and consequent disturbance of the pavement (fig. 44).

Welded Joints.—This form of joint is considered in the chapter on Rail-bonding and Welding.

Tie-bars.—The tie-bars, which are used for maintaining the gauge or distance between the rails constant, consist, as a rule, of flat bars made of wrought iron or mild steel. These are usually fixed edgeways, as shown in fig. 45. In the case of wood paving, however, they are often laid flat.

More recently angle-iron has been used for the tie-bars, especially where the rails have a very high section. In order to maintain the gauge exactly, small wedge distance-pieces are inserted between the end of the tie-bars

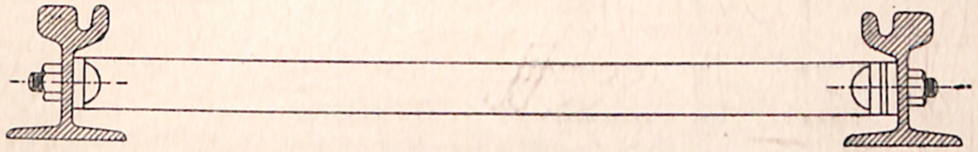


Fig. 45.—Standard Form of Tie-bar

and the rails, as shown in fig. 46. Many tie-bars have one end turned and screwed with a Whitworth thread, usually $\frac{7}{8}$ inch diameter, the other end being notched; some bars are screwed at both ends. Two nuts and washers are required at the screwed ends. The tie-bar holes in the rails are slotted to a size of about 3 inches long by 1 inch wide. This allows of a certain amount of play, in order that the tie-bars may be placed between a line of setts, and thus save cutting the same. The tie-bars are usually

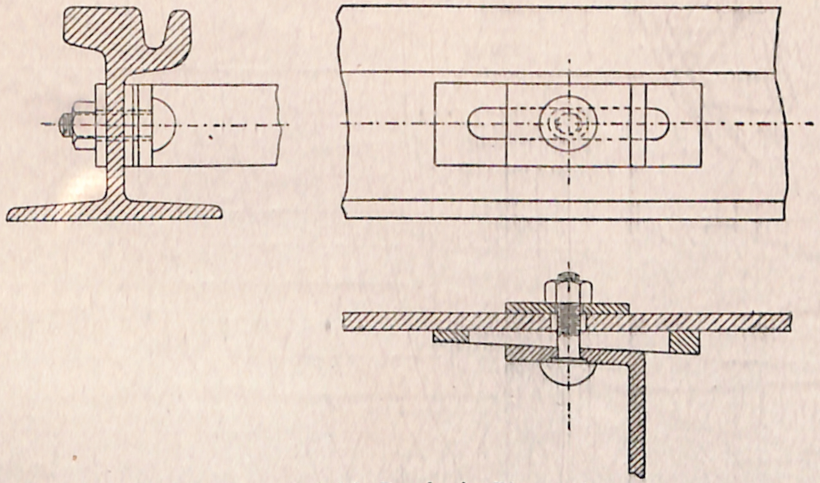


Fig. 46.—End of the Bar, showing Distance-piece

spaced about 7 feet 6 inches apart, the first tie-bar in each rail being placed about 2 to 3 feet from the end.

Foundations and Paving.—In macadamized roads the tramway rails are laid flush with the level of the road, and simply packed underneath with the material taken from the road surface. With shallow rails such a simple laying in the body of the road is satisfactory enough, but with the high profile used at the present day a deeper packing is required as a bedding under the rails. It is obtained in this way: a small space under each rail is packed, or the packing is carried right across the track and under both rails (see fig. 47). The latter arrangement ensures a better rolling of the track bed. The addition of the rails to the body of the street is then simply performed, without anything further than filling in and rolling down the broken stone surface of the road.

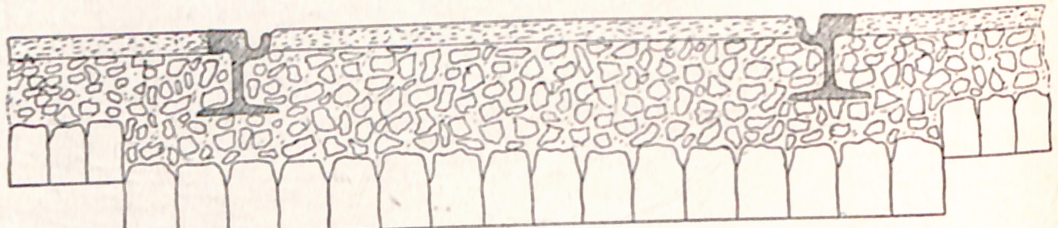


Fig. 47.—Tramway in a Macadamized Road

In busy streets a better form of paving is required, the space between the rails and to a short distance on each side being laid with setts, usually of granite (see fig. 48). In causewayed streets the rails are laid in a similar manner to that adopted for macadamized roads, i.e. in a gravel bedding with a layer of packing under the rails, and also, at times, with a concrete

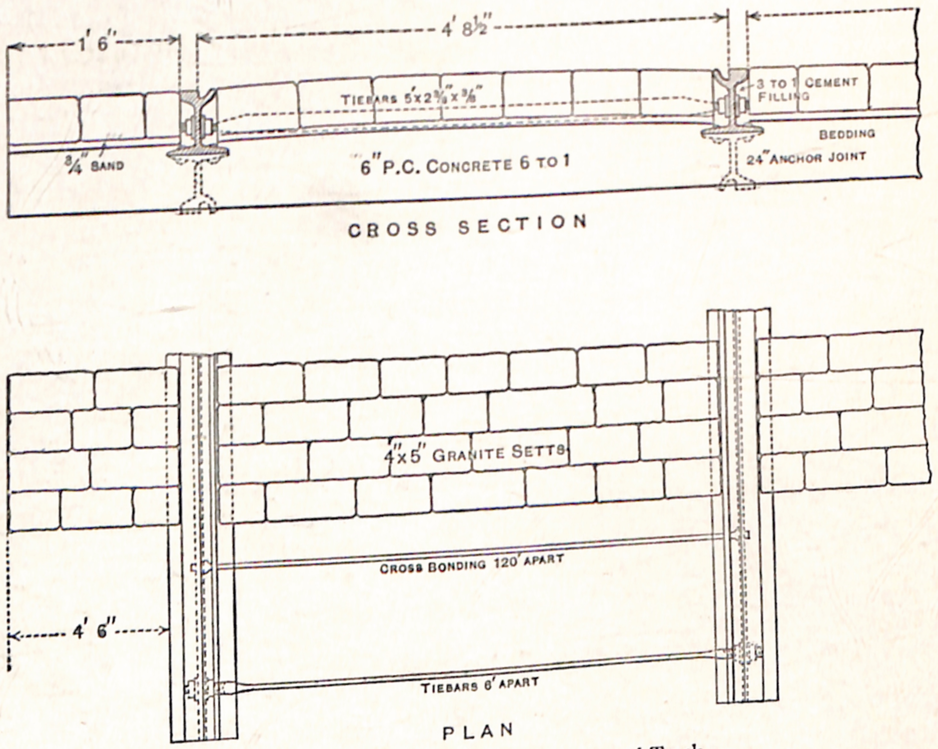


Fig. 48.—Plan and Section of Granite-paved Track

foundation. The rails are chosen of such a height that the causeway stones of the street surface can rest on the foot of the rails. The space between the web of the rail and the setts is filled with gravel, sand, concrete, or a rich cement mortar.

The laying of a tramway line in a noiseless paving—i.e. an asphalt or wood paving—is not very satisfactory. With this method of laying, the

street surface always rests on a layer of concrete. Since the height of the asphalt layer and of the wood blocks is nearly always less than that of the rails, a special trench must be made in the concrete bed for the reception of the rails, and at the same time the layer of concrete under the rails must be made up to a corresponding thickness—at least 6 inches in most cases (fig. 49). There is sometimes a layer of cement inserted between the rail and the concrete foundation, the cement being poured into the space between the rail and the asphalt.

In a newer form of construction the rails are laid on re-enforced concrete slabs which are made in the factory and are very strong. These slabs are laid at a distance of 3 feet 3 inches to 4 feet 5 inches apart in the trench, and the rails placed directly on them. The iron bars embedded in the slabs project at the ends, so that after concrete has been poured in

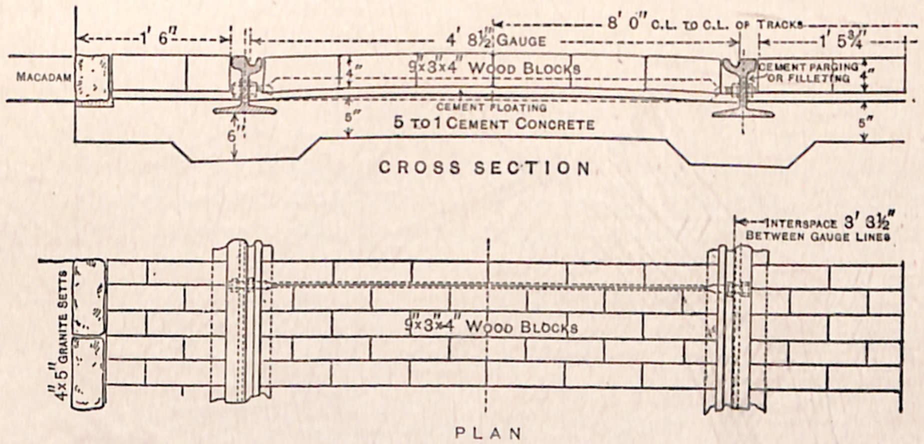


Fig. 49.—Plan and Section of Wood-paved Track

between them a complete junction results. A special difficulty is presented with asphalt paving of getting a satisfactory union of the rails with the street surface. A whole series of different methods have been tried, e.g. pouring melted asphalt round the rails, laying asphalt slabs alongside the rails, bordering the rails with wood blocks, stone setts, cast-iron setts, or stone slabs or sleepers, &c. These all prevent, to a certain extent, the formation alongside the rails of ruts which are formed by the wheels of other vehicles running partly on the car lines, these wheels having, as a rule, a gauge somewhat less or somewhat more than that of the rails.

In America, where a cross-sleeper construction is adopted, the sleepers are usually laid on a bed of gravel or broken stone. Between the top of the sleepers and the paving-stones a space is left which is filled in with gravel or sand.

With asphalt paving the sleepers are often completely embedded in concrete. In these cases stone slabs are usually placed alongside the rails.

Drainage of the Track.—Since water gathers in the grooves of the rails and is apt to destroy the foundations, especially in the lower parts of the routes, it is usual to arrange for the draining away of the water at these points.

There are various arrangements of draining the grooves in use. In every case an outlet is made for the water by a slot in the foot of the rail (with Haarmann rails), or in the bottom of the groove (with solid grooved rails); from this a pipe leads the water away to the main sewers. In some special cases a special cast-iron chamber is situated between the rails and covered with a grating, the water is then drained from this chamber through a pipe, and the mud which remains is cleared out periodically.

Arrangement of Points or Switches.—With tramways the arrange-

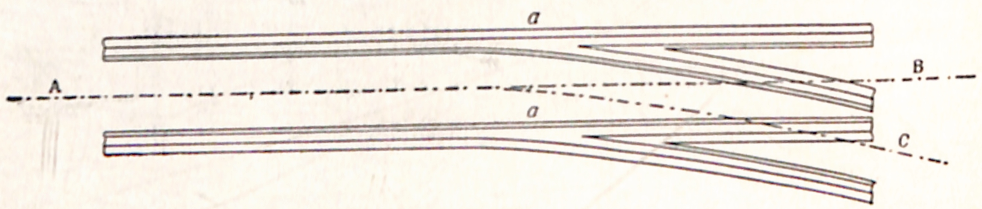


Fig. 50.—Switch with Fixed Points

ments of points mostly made use of are the simple left-hand switch, the simple right-hand switch, and the simple symmetrical double-curve switch. It is sometimes impossible, however, to avoid using the symmetrical three-curve switch; still, as far as possible this is overcome by the use of two simple right- and left-hand switches following one another. The radii of the switches vary from 60 to 160 feet, the use of the smallest radius being usually due to restrictions of space.

The angle of the crossing is chosen so as to have an inclination of

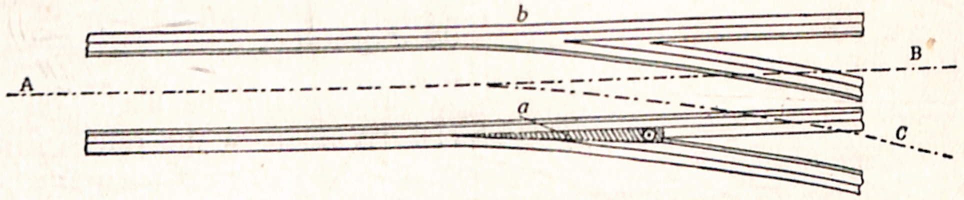


Fig. 51.—Switch with One Movable Tongue

about one-third or one-sixth, and the tongues are mostly 6½ to 10 feet long.

Deflecting Devices.—

1. *Fixed Points.*—Switches without tongues or with fixed points were used with horse tramways. Fig. 50 shows diagrammatically such an arrangement. The grooves branch off at the point *a*, the running edge being interrupted here. To move in the direction of the points presents no difficulty, but to move against them, especially in the direction A–C, can only be done by the horses drawing the car sideways to a considerable extent. This form of switch is now only used when the cars either move with the points or only against them in the direction A–B.

2. *Switches with One Movable Tongue.*—The arrangement of a switch with a tongue is shown in fig. 51. By means of the tongue *a* one side of

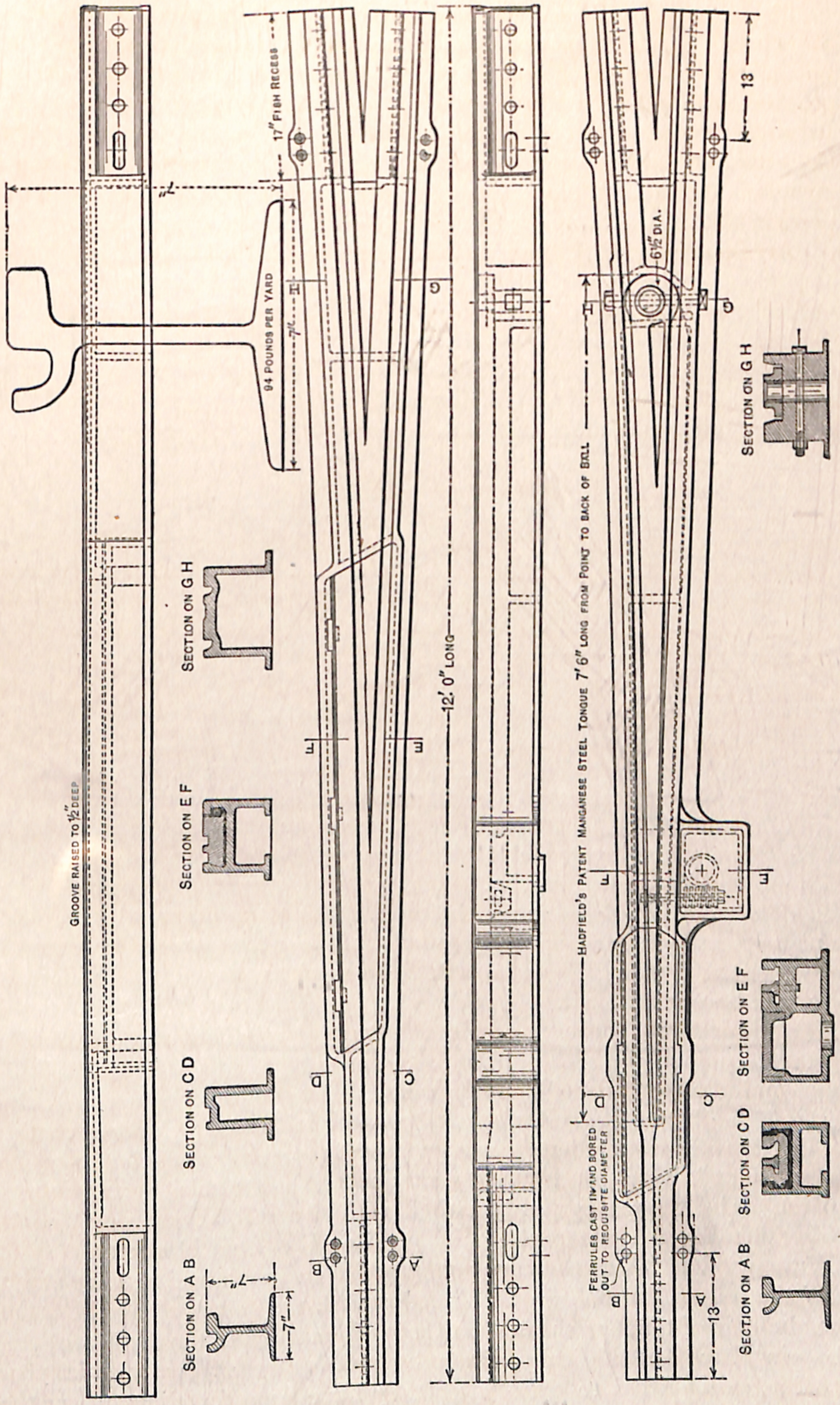


Fig. 51a.—Plan showing Points 12 feet long with Renewable Manganese Wearing-centres

the rail track presents, for all directions of travel, an uninterrupted running edge. Driving in the direction of A–B, or A–C, is ensured by setting the tongue for the straight or the curved track; for driving in the direction B–A, or C–A, the tongue is forced by the flanges of the front wheels into the right position. In order to make certain of the correct guiding action of the movable tongue, on the car wheels, the switch *a* is laid in position before the switch *b*. If, as is often the case, the cars only move in the directions A–B and C–A, then the tongue *a* can be held in the position for the direction A–B by a spring; the cars coming from the direction of C force open the point, and, after they have passed, the spring draws the tongue back into its original position again. Fig. 51*a* shows a standard form of point with renewable manganese wearing-centres.

3. *Switches with Two Movable Tongues.*—In consequence of the increased adoption of electric traction, switches with two movable tongues are coming more and more into use. A diagrammatic representation of

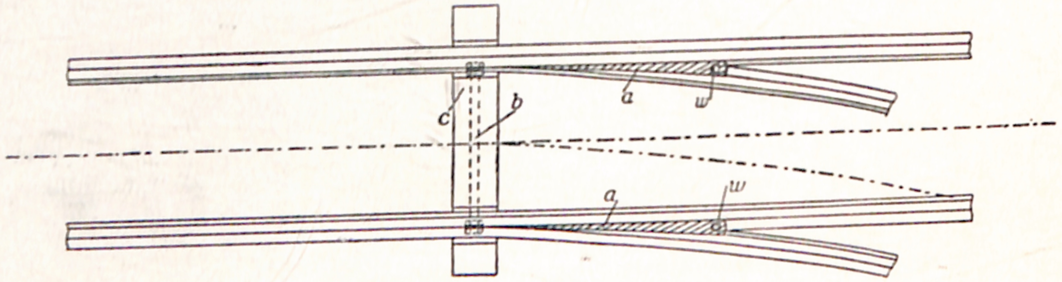


Fig. 52.—Switch with Two Movable Tongues

such a switch is shown in fig. 52. Both tongues, *a–a*, are coupled together by a rod *b*, which is situated in a cast-iron box *c*, just below the street level. As a supporting slide for the tongues a cast-steel block is used, mostly of a ∏ shape, with strong webs. The tongues themselves are formed of steel, and turn about a pivot *w*.

In order to avoid the point of the tongue being too sharp, which would diminish its carrying capacity, the stock rail is either shaped to receive the tongue or, as with railway switches, the stock is planed out below and the tongue housed under it.

The formation of the tongue-piece is easily carried out with twin rails by gradually increasing the space between the rails, and inserting the tongue and the supporting block between them. With one-part rails the guard rail is planed off and a special counter rail fitted. More recently, also, in tramway work, there has been used in special cases the so-called "spring point", which does away with one and all special arrangements of pivot. The tongue is firmly united with the rail at its root, and is only retained in the one position by reason of its own elasticity.

With switches where the cars are only driven in both directions along one of the routes, and only in the direction with the switch along the other route, the pair of tongues are held in the position suitable for the first route, and spring back automatically, either by means of their own elasticity or that of a spring fitted to them, after they have been forced open by the

flanges of the wheels of a car moving in the direction of the switch along the other route. The tongues are here either each operated by a separate spring or by a spring inserted to act on the rod connecting the two tongues, which thus operates on both at the same time. The mechanism of the spring and coupling-rod is in both cases enclosed in a sunken case in the paving, and the cover of the casing is fluted so as to prevent people and horses slipping on it. If a point be required through which the cars can be driven in any direction, such an arrangement as the above cannot be used, since the tongues must always be brought into the right position before the car passes through the switch.

As a rule, such points are moved into the required position by hand by means of a rod or lever, termed a "point-shifter". This is usually done by the driver from an open platform, but with totally enclosed ones it is done by the conductor, who for this purpose must leave the car. At switches where the traffic is heavy a special pointsman (or boy) is placed.

In order to avoid the disadvantages of setting a point by hand, within

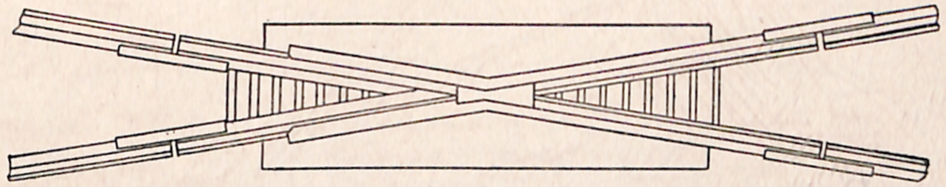


Fig. 53.—Form of Frog for a Grooved Rail

recent years, where the traffic is very heavy, an electrical mechanism is erected which can be put into operation by the car-driver. The principle of this arrangement consists in that in driving to the switch a special contact arrangement, which is fixed in the overhead line before the switch, can be set so that the tongue can be operated by one or two electromagnets placed alongside the switch. These magnets are usually placed alongside the switch in the paving.

In order to let the car-driver know in the dark the position of the tongue, a light is sometimes used which indicates the direction in which it is set.

Diamond Pieces or Frogs.—Diamond pieces or frogs are made either of chilled cast iron or, like the tongue pieces, are built up out of the rails. This last arrangement ensures an equal wear of the whole permanent way, and is usually preferred nowadays.

One form of frog for a grooved-rail line is shown in fig. 53. Of the two points required in the frog only one becomes worn to any extent by the car wheels passing over it.

In order to obtain smoother driving over the gap in the frog, the wheels are allowed to ride on the flanges. For this purpose an "insert piece" with a rising groove-bottom, or with wedges laid in the grooves, or rails with flat grooves, are used, and the joining of the latter with the normal grooved rail is reached by a gradual deepening of the groove. Cast-steel frogs with changeable points made of manganese steel are sometimes used in Britain and America. Fig. 54 shows a crossing built on these lines.

Some frogs, like switches, have movable tongues held in position by a spring.

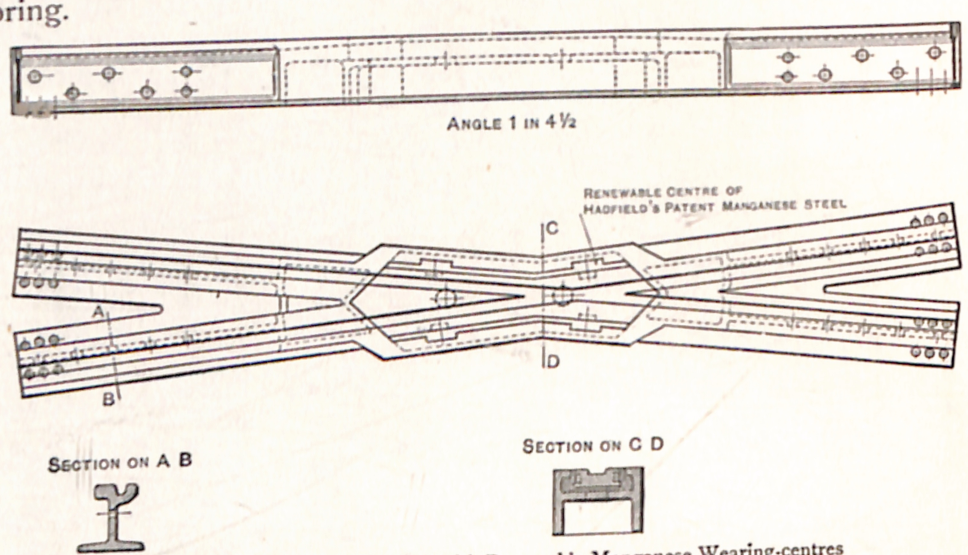


Fig. 54.—Plan showing Crossing with Renewable Manganese Wearing-centres

Crossings.—A rectangular tramway crossing is shown diagrammatically in fig. 55. At the points *a–a–a–a* special pieces of chilled cast iron with interchangeable manganese steel pieces are inserted. Fig. 56 shows an oblique crossing. In this the rails of the principal line have their treads carried right through, and those of the other line are broken. Sometimes the crossing pieces are first laid in place and cast iron poured round them, and, as with the frogs, in order to allow of smooth running the groove has a special wedge piece inserted, to allow of the wheel riding on its flanges over the crossing. Fig. 57 shows such a wedge piece inserted for this purpose.

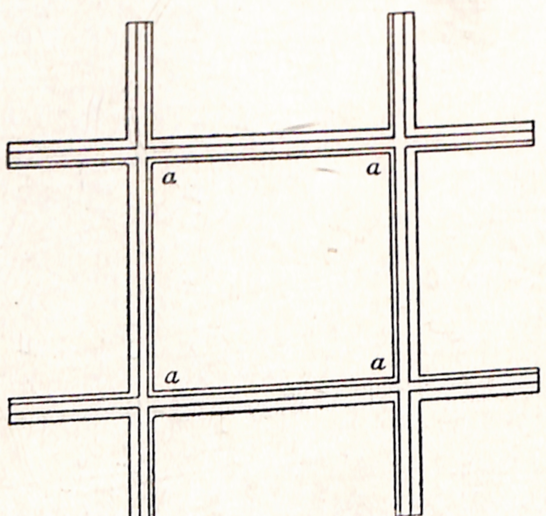


Fig. 55.—Rectangular Tramway Crossing

Climbing Points and Emergency Track.—While repairing one of the tracks, it is necessary at times to divert the traffic on to the other line for a short distance alongside it. A temporary crossing must therefore be laid down, which allows of the cars climbing out of the grooves of the one set of rails to reach those of the other.

At points *a* and *b*, fig. 58, wedge pieces are laid in the rails which lead the wheels on to the emergency track. The climbing point consists usually of a fixed and a movable tongue and a frog. As a rule, a grooved rail of

a flat cross-section, as shown in fig. 59, is used for the emergency track, so as to have the least possible raising of the cars. With single-track lines a

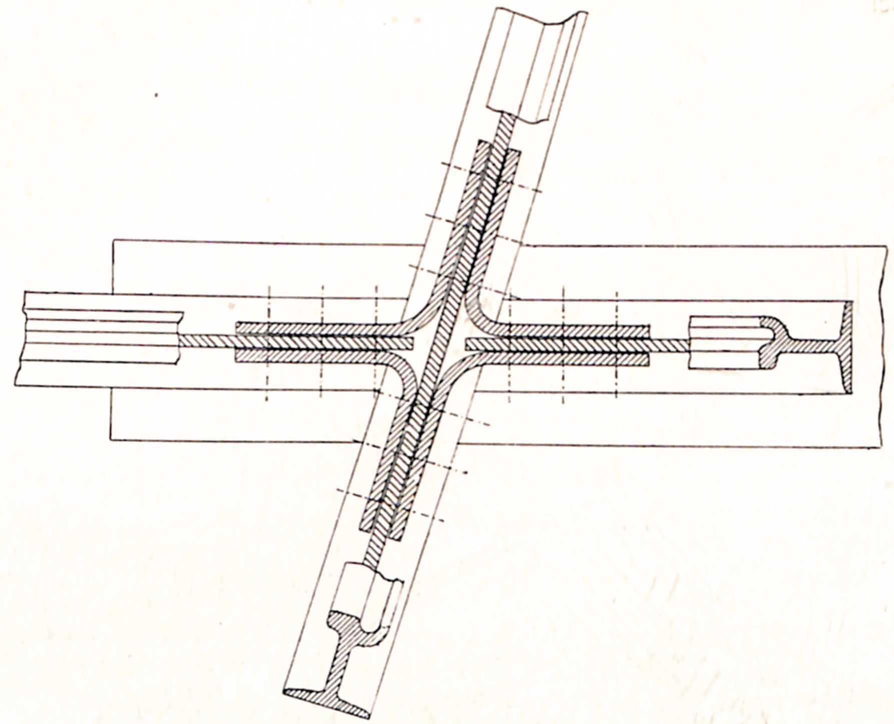


Fig. 56.—Oblique Crossing

complete emergency siding is sometimes built up in this way; this emergency track being simply laid on the road surface and the distance apart of the rails maintained by tie-bars.

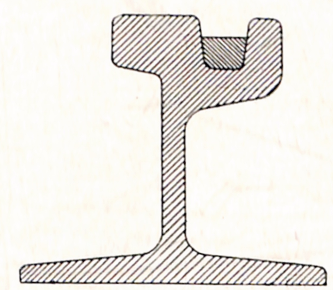


Fig. 57.—Wedge Piece inserted for Running On

When fire hose and other pipes are temporarily placed across the track, special pieces called "hose-bridges" are placed over them, which enable the cars to climb over the top without damaging them.

Preparation of Plans.—Before proceeding to the actual laying of the rails, a careful survey should first be made of the proposed routes, and completed to a scale of not more than 50 feet to the inch. The kerb and building line should be shown on the plan, and in cases of narrow streets, where a space of less than 9 feet 6 inches

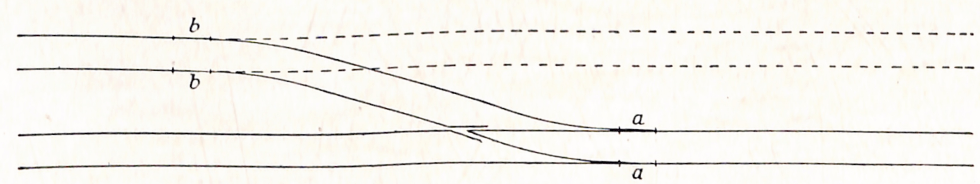


Fig. 58.—Arrangement with a Climbing Point

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

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

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

CHAPTER IV

RAIL BONDING AND WELDING

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

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