"improvements which you introduced at so early a date into "electric machines you placed the manufacture of the dynamo "on a truly commercial basis, and prepared the way for the "great development of electric lighting which has marked the "closing years of the present century. On behalf of our country "we beg to thank you, and beg to express our admiration for "the work which has secured to you world-wide recognition "and lasting fame.

"Signed on behalf of the Institution of Electrical Engineers:

"JOSEPH W. SWAN, *President.*

(Delegates) { "W. E. AYRTON, *Treasurer.*
"S. P. THOMPSON.

"W. G. MCMILLAN, *Secretary.*"

The medals due to the various subscribers will be received by the Secretary when they are ready, and distributed.

The following papers were then read:—

EARTH RETURNS FOR ELECTRIC TRAMWAYS.

By H. F. PARSHALL, Member.

Mr. Parshall. Considering the small difference of potential at which electrolytic action may take place, a matter of primary importance in electric tramway systems in which the rails are used as return conductors, is that in reference to the rate of fall of potential, and the difference of potential between the rails and the general mass of earth, the magnitude of which may vary according to such local conditions as the locality of gas and water pipes, the conductivity of the earth between the rails and such pipes, and the conductivity of the pipes themselves.

The exposed surface for leakage of the track is very great; thus in the ordinary four-track tramway system there is some 50,000 feet per route mile. With so great a surface, and with, as is generally the case, considerable conductivity of the concrete and earth, a large fraction of the current may be diverted from the rails, even in short lines, and with a maximum drop as small as that specified by the Board of Trade.

Thus, in tests recently carried out in a line some eight miles long, it was found, by cutting the track at the middle of the line and inserting an ampere-meter, that some 60 per cent. of the current was returning through the earth itself. Tests made as to the conductivity of the earth return showed as a whole that it was about one and a half that of the rails, bonds, and fish-plates, which would indicate that on an average about 33 per cent. of the current was leaving the rails. In other words, the voltage drop in the earth return was but two-thirds of what it would have been had the current been wholly in the rails. Mr. Parshall.

In laying the rails, therefore, it seems desirable to adopt such methods of construction as will, to a considerable extent, insulate the rails from the adjacent mass of earth. The conductivity of the earth is considerable, and with differences of potential up to the limit established by the Board of Trade is so great that, in the cases I have examined, stray currents are not diverted from the mass of earth by gas and water pipes. I have made tests by cutting the rails and measuring the currents at different points, and, so far as could be determined, the neighbouring gas and water pipes were not traversed by the current. In one special case two lines of the tramway formed two sides of an acute angle triangle, and a very large water main formed the third side, and, even though some 50 per cent. of the current did not come back through the rails, the tests showed beyond doubt that there was no current whatever coming across the third side of the triangle through the water pipe. Of course, with the small difference of potential common in practice in this country, the C.E.M.F. of polarisation which accompanies currents flowing between conductors when electrolysis takes place, is an important element in determining the law of current-flow.

The tests carried out by the writer have, in every case, shown that the joint conductivity of the rail and of the earth is considerably greater than that of the rails themselves. For this reason there exists the necessity of determining the conductivity of the rails, fish-plates, and bonds, before the track is laid in the earth, so that after a roadway is completed the measured drop may be taken as an indication of what percentage of current is straying from the rails; so that tests made from time to time may indicate the general condition of the bonding.

In general it is desirable that the earth return be isolated to

Mr. Parshall. the greatest degree practicable from any other metallic conductors liable to be affected by electrolysis. In some cases, however, where the drop in the earth return has been comparatively great, attempts have been made to prevent electrolysis by bonding the rails to the adjacent gas and water pipes. The results have been more or less satisfactory. It is obvious that, if the rails and adjacent gas and water pipes can be kept at the same potential, electrolytic action can be effectively prevented. Considering, however, the very considerable conductivity of the earth, it would seem doubtful whether such bonding would prove effective with any considerable drop in the rails, since in this case stray currents would flow from one part of the system to another, and at such a difference of potential as would cause electrolysis.

In the case of lead-sheathed cables running parallel to earth returns of tramways the results have been entirely satisfactory, and are conclusive, since, in the absence of bonding, the lead sheathing was rapidly eaten away. This instance, however, is not to be relied upon as an indication that it would be safe to carry out the same process in dealing with gas and water pipes. The lead sheathing is homogeneous, of comparatively high resistance, and with small surface exposed to the earth, whereas the reverse holds true with gas and water pipes as ordinarily laid down. I have no doubt that there are cases in which effective bonding of the rails adjacent to conductors might give entirely satisfactory results, but I should hesitate to make any general recommendation to this effect, since in very many cases a result directly opposite might be obtained.

There is such a difference in soils—first, as to corrosive properties; second, as to electrical conductivity—that a general rule which would prevent electrolysis in every case would be unnecessarily severe, and in many cases prohibitive. It is obvious that, where currents stray generally into the earth so as to enter metallic conductors, the difference of potential should not be allowed to exceed that at which electrolysis begins, + the drop in the earth itself.

In a given system of distribution the controllable features in the earth return are practically limited to the method of jointing the cross section of the rails, and to the chemical composition of the rails.

The chemical composition of the rails cannot be altered greatly, since rails low in carbon, but of high electrical conductivity, are found to wear away so rapidly that high carbon rails are a practical necessity. Mr Parshall.

The cross section of the rail is in practice largely determined from mechanical considerations, and in the best practice rails of from 80 to 100 lbs. per running yard are used.

The method of making the rail joints is practically, then, the only factor controlling the resistance of the rail return that is susceptible of wide variation in practice.

The electric welding of the rail joints has been tried in the United States, but thus far the results have not been such as to encourage manufacturers to advocate the use of the system, or the tramway companies to adopt it.

The joints in electrical tramway work are equally objectionable from either a mechanical or electrical point of view, so that a system of perfectly welded rails would meet with general favour. In practice the effect of temperature in causing expansion and contraction has been noticeable in long lengths of welded rails; but the effects thereof have not been of such a serious nature as might be expected from the range of temperature.

From the reports I have at hand, it appears that there were unexpected results of the welding process that made themselves evident in the course of time.

First, the electrical conductivity of the welded section was less than that of a solid rail.

Second, the portions of each rail near the weld were so softened as to wear away unevenly.

Another unexpected result was that, owing to the sudden increase and decrease in temperature, the rail took a very high temper at the weld, so that its power to withstand shock was decreased.

To the writer's mind it is not improbable that these mechanical difficulties could be overcome. Welding apparatus of sufficient capacity, however, is costly; and it is frequently difficult to arrange for the amount of power required; so far, therefore, the process has not been employed in this country.

Mr. Parshall. Another method of somewhat the same nature as the process of welding is that known as the "cast weld," or the "Falk joint." This joint is made by pouring molten metal into a metal mould clamped round the rail joint. The surfaces of the cast metal that come in contact with the mould and with the rail joint are chilled, and are thus prevented from forming a perfect weld. I believe it has been asserted that a weld is effected. It seems, however, extremely doubtful, since without the use of a flux a weld is almost impossible between cold wrought steel and molten iron. The rail expands after the metal is poured around it, and remains expanded until after the cast iron has set, and finally resumes its former size. This affords a slight clearance for expansion and contraction, and accounts for the mechanical success of the joint, which, if carefully applied, makes when new a perfect mechanical track; although, in the writer's mind, the difference of resilience between the part surrounding the casting and the remaining part of the track may eventually cause uneven wearing away of the rail.

The clearance above spoken of undoubtedly admits a certain amount of moisture, so that by the formation of oxide the resistance of the joint increases in the course of time. From the results of tests which I have at hand, it also appears that the electrical resistance of this joint, even when new, varies considerably; so that, considering the low voltage restrictions in this country, it should be used in connection with an efficient form of bond. Owing to the rigidity of the joint, however, copper bonds will undoubtedly be found more durable in conjunction with it than with a fish-plate form of joint.

Bonds.

The bonds generally used up to this time are of the pressure-contact type, and in making any general statements this is naturally assumed as the basis.

In the discussion of a paper read some time ago before this Institution, the writer pointed out that, according to experience with pressure contacts in central station work, 100 amperes per square inch had been found the limit in best central station practice; and that, considering the trying conditions to which bonds are subjected in the earth, one-half of this value would more likely be satisfactory. Mr. Parshall.

In actual practice I have found it advisable to work to a still lower limit, and in most of the systems which I have designed the current-density at surface of contacts does not exceed 25 amperes per square inch. Experience shows this limit a safe one, and that the contact resistance is negligible as compared with the resistance of the rails.

Considering the complicated phenomena accompanying a junction of copper and iron, in respect to the difference of potential caused by the contact of dissimilar metals, and the effect due to a current passing between dissimilar metals, it seems in the normal case that all E.M.F.'s would balance each other, since, in the case of the current keeping uniformly through the rails, the E.M.F.'s at the positive ends of a bond are balanced; and in the case of one end of a bond losing its contact the additional resistance would be greatly in excess of the unbalanced contact E.M.F.

The design of copper bond should be largely in reference to the permanency of the contact surface. If there is any working between the surfaces, sooner or later there will be a film of oxide, so that the value of the contact will be destroyed. The working of the surfaces may be caused by heating from excessive current-density, or by lack of flexibility in the bond. Numerous types have been forthcoming. Many of the bonds brought forward during the last two or three years have been designed with a recognition of the importance of greatly increasing the area of the contact surface, as compared with the cross section of the body of the bond itself.

It is beyond the scope of this paper to discuss all the different types of bonds that have been brought forward from time to time. Samples of many of the different types are exhibited. The copper bonds that the writer has tested, since they have been more generally used in this country, are either of the "Chicago," "Crown," or "Columbia" type, samples of which are before you.

Flexible bonds are found desirable for use where the mechanical conditions are such that short bonds can be used, in which case the added resistance of the bonds to the track can be made as low as 5 per cent., or less. Bonds of this type have been frequently used in the United States, and with good results when

Mr. Parshall. the ends are made of drop forged copper. When, however, the ends have been made of cast copper, and cast on to the conductors, the results are not generally satisfactory. The resistance of cast copper is so much greater than that of drawn copper that it is not best suited for use in bonds. Further, the union between cast copper and drawn copper wires is imperfect, so that the electrical resistance is much higher than between two pieces of pure copper fused together.

The remaining type of bond that I propose to discuss is that known as the "plastic" bond, which was invented by Mr. Edison several years ago. From the results obtained from a line bonded over five years ago, it appears that this plastic alloy, which consists of mercury and other ingredients, as to the nature of which I am uninformed, is much more permanent than might be expected from its mechanical nature. The bond is placed between the fish-plate and the rail, in a cork receptacle, which is compressed to about half its thickness when the fish-plate is drawn up tightly.

The amount of copper required materially to increase the conductivity of well-bonded rails is so great that, in ordinary practice, auxiliary track feeders are not commercially practicable, unless they be connected in circuit with a source of E.M.F. to compensate for the drop in the feeder, so that this may exceed that in the track return.

I believe Major Cardew was the first to suggest employing E.M.F.'s in feeders to compensate for the drop therein. In the arrangement, however, of the earth return as originally devised by him, it was necessary to use generators of different E.M.F.'s in the generating station. I have used in my work a generator that is separately excited through a coil in series with the trolley feeder, so that the voltage generated by the armature is directly proportional to the current-output, provided the field magnet be not saturated. The armature is in series with an insulated feeder connected with the rail at whatever point it is necessary to take off current. The results in practice are most satisfactory. It has been found that the machine works perfectly automatically, and limits the voltage drop in the earth return to any desired amount by an adjustment of a rheostat in parallel with the field-magnet coil. Fig. 1 gives a diagrammatic representation of the system.

In a system that I have recently designed to carry some 250 Mr. Parshall.
cars, I propose to employ several earth generators feeding in from several points in the system. Pairs of test wires are run back to the station from various points, one of the test wires being connected to the track return, and the other to adjacent earth plates. The earth generators in the station will be adjusted from time to time, according to the difference of potential between the earth plates and the earth return. As far as possible the adjustments will be made so that the two may be kept generally over the system at the same voltage. Whatever

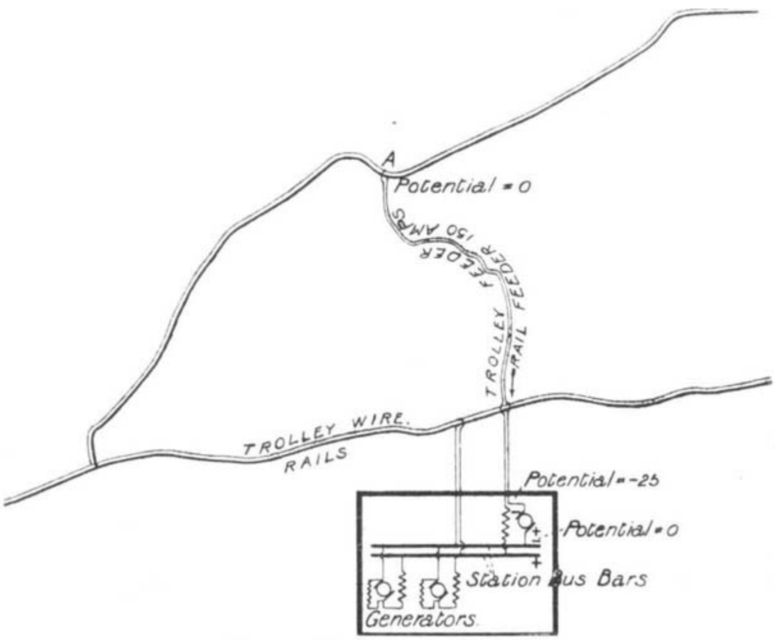

FIG. 1.—Return Booster System.

difference of potential there may be between the two, will be such that the earth return is, in general, positive to the neighbouring water or other pipes, since in this case whatever electrolysis takes place will be in the track return itself.

STEEL RAILS.

The percentages of carbon, manganese, &c., in steel rails have varied considerably at different times; and there are, even now, wide variations in the practice of different companies, and in different countries.

Mr. Parshall. It may be said that English rails some years back would commonly contain the following:—

Carbon	0·25 to 0·35
Manganese...	0·8 „ 1·0
Silicon	0·05
Phosphorus	0·06
Sulphur	0·06

Of late years the percentage of carbon has increased. One large railway company specifies:—

Carbon	0·4 to 0·5
Manganese...	0·95 „ 0·85
Silicon	0·10 „ 0·06
Phosphorus	0·10 „ 0·08
Sulphur	0·08

In American practice the carbon runs still higher, as will be seen from the following:—

Carbon	0·45 to 0·55
Manganese...	0·8 „ 1·0
Silicon	0·10 „ 0·15
Phosphorus	0·06
Sulphur	0·06

In France yet higher percentages of carbon have been tried, running up to nearly 1 per cent.

The results are shown in the following table of trials, of sample sections of steel rail of varying compositions which were furnished for testing purposes:—

Carbon.	Manganese.	Silicon.	Phosphorus.	Sulphur.	Resistance compared with Copper 20° C.	Resistance of 1 Mile 1 sq. in. Sectional Area at 20° C.
0·378	0·550	0·181	0·040	0·041	10·8	0·468
0·446	0·568	0·188	0·046	0·044	11·1	0·482
0·536	0·592	0·201	0·051	0·059	11·3	0·490
0·568	0·608	0·204	0·053	0·061	11·4	0·495
0·588	0·632	0·214	0·056	0·065	11·5	0·499
0·610	0·650	0·220	0·062	0·071	12·9	0·560

Eight 76-lb. track rails, tested in place after $2\frac{1}{2}$ years' use, Mr. Parshall.
gave the following results :—

	Resistance compared with Copper 20° C.		Resistance of 1 Mile 1 sq. in. Sectional Area at 20° C.
Test No. 1	11·3	...	0·490
" " 2	10·3	...	0·447
" " 3	10·1	...	0·438
" " 4	10·7	...	0·464
" " 5	9·65	...	0·419
" " 6	10·07	...	0·437
" " 7	10·25	..	0·445
" " 8	10·50	...	0·455
Average ...	10·4	...	0·45

Two old 65-lb. rails, much worn, tested in place :—

	Resistance compared with Copper 20° C.		Resistance of 1 Mile 1 sq. in. Sectional Area at 20° C.
Test No. 1	11·7	...	0·508
" " 2	12·3	...	0·534
Average ...	12·0	...	0·52

High values would be expected owing to the wearing of the rail, which is not allowed for in the calculations.

Two new 90-lb. rails, tested in place :—

	Resistance compared with Copper 20° C.		Resistance of 1 Mile 1 sq. in. Sectional Area at 20°C.
Test No. 1	10·6	...	0·460
" " 2	10·4	...	0·451
Average ...	10·5	...	0·455

A $66\frac{1}{2}$-lb. rail not laid :—

	10·0	...	0·434

Bonds.

The current flows across the joints partly through the fish-plates, and partly through the bonds. The resistance of the fish-plates is a variable quantity, but all tests on rails in use have shown that they contribute considerably to the conductivity of the joint.

For the bonds themselves the following tests have been made :—

Mr. Parshall.

(1) Conductivity tests on bond copper.

(2) Resistance due to contacts.

(3) Resistance due to current "gathering" from other sections of rail to enter the bond terminal.

1. *For Conductivity* the Chicago bonds in the different tests have shown practically 100 per cent. of the conductivity of pure copper. A flexible Crown bond showed only 93 per cent. conductivity. The Columbia bonds in the cases tried showed about 90 per cent. conductivity.

2. *Resistance due to Contacts.*—Measured from the potential difference between two points very close together, one on the bond terminal, the other on the steel. Experiment showed the following results :—

——	Test.	Resistance per Bond (2 Terminals).	Resistance of 176 Joints, or per Mile with 30-ft. Rails.	——
		Ohms.	Ohms.	
Chicago Bonds ... ⅞-in. terminals in ½-in. web. 1·37 sq. in. contact area.	1	0·00000197	0·000347	Bond and hole very clean.
„ „ „	2	0·00000215	0·000379	„ „
„ „ „ „	3	0·0000025	0·000440	Bond not cleaned; hole freshly reamed, but oily.
„ „ ...	4	0·0000080	0·00141	Bonding not supervised.
Crown Bonds	5	0·0000080		„ „
⅞-in. terminals in 7/16-in. web. 1·2 sq. in. contact area.		0·0000028		
Total ...		0·0000108	0·00190	
Crown Flexible Bond...	6	0·0000422		Bonding not supervised; bonds afterwards found to have been put in rusty hole.
⅞-in. terminals in 7/16-in. web. 1·2 sq. in. contact area.		0·0000518		
Total ...		0·0000940	0·0165	
Columbia Bond ... In ⅞-in. hole in ½-in. web. 1·37 sq. in. contact area.	10	0·0000072	0·00127	Hole clean; bond untouched.
„ „ „	12	0·0000095	0·00167	„ „
„ „ „	13	0·0000077	0·00136	Hole 4 days old; bond untouched

Tests 4, 5, and 6 show that want of care in bonding may lead to serious increase in contact resistance. Mr. Parshall.

From the tests made it may be said generally that bonds properly applied—that is, clean bonds in bright reamed holes, put in with a proper fit with a drift driven square—have practically negligible contact resistance. Experiments showed that, at 100 amperes per square inch at least, the drop in the contact surface was inappreciable compared with that in the bond and in the rail. The same was found true with bonds—samples of which are exhibited—that have been in use for over two years, when the current-density has been limited as stated. Experiments on this point have been carried out to a considerable extent, since it has been frequently stated that the contact resistance is a very appreciable factor, and that it can be greatly lessened by amalgamating the surfaces. This will not be the case except when there is carelessness in putting the bonds in place.

3. *Gathering.*—The current may be supposed to flow uniformly through the rail at all parts, a foot or so from the ends or from bonds. At a bond, however, it has to gather, and it is scarcely to be expected that, say, 16 inches of rail terminating at a bond, should show the same resistance as 16 inches in the middle of the rail.

Tests on a bar of steel 3 inches × ½ inch showed "gathering" at the two bond terminals added resistance equivalent to a total of about 1 inch of the bars.

Tests on an 83-lb. rail showed "gathering" resistance equivalent to 3·4 inches of rail at each contact, or a total of 6·8 inches per joint.

JOINTS.

The conductance of the joints depends, as stated, on both bonds and fish-plates.

The first have been discussed already.

The second have a very appreciable effect, even with rails that have been in use for some time.

The following table shows the results of a number of tests made partly in the laboratory and partly on track in use :—

Mr. Parshall.

Laboratory Tests.	Additional Resistance due to Joint.		
	Ohms.	Inches of Rail.	Resistance of 176 Joints per Mile, or with 30-ft. Rails.
83-lb. rail; six tests; no bonds, fish-plates uncleaned, and not fully tight	0 0000095 to 0·000081	10 to 87	0·0017 to 0·0143
Average	0·000039	34	0·0068
Single 0000; 30-in. bond only (calculated)	0·000101	109	0·0178
83-lb. rail, with one 30-in. Crown 0000 bond, plates well tightened	0·0000024	3	0·00041
Same with fish-plate removed	0·000106	114	0·0187
This bond had too great contact resistance. See Contact Test No. 5.			
Tests on Rails in Use.			
76-lb. rail; one 30-in. 0000 Chicago bond and fish-plates	0·0000307 to 0·0000622	32 to 65	0·0054 to 0·011
Four tests made without disturbing track, *average*	0·000043	45	0·0076
76-lb. rail as above (track 2½ years old); four tests	0·0000275 to 0·0000843	28 to 80	0·0048 to 0·0148
Average	0·000046	48	0·0081
Single 30-in. 0000 Chicago bond only (calculated)	0·000103	114	0·0181
Old 65-lb. rail; one 30-in. 0000 Chicago bond, fish-plates not tight	0·000069	57	0·0121
Above with fish-plates removed	0·000090	74	0·0158
Above with fish-plates replaced and well tightened ...	0·0000473	39	0·0083
New 90-lb.; two 32-in. 000 Chicago bonds and plastic to one fish-plate	0·0000081 0·0000040	10 5	0·0143 0·0071
Average	0·0000060	7½	0·0105
Fish-plate added to conductivity.			

The above values show that the contacts had not deteriorated in any way in the two and a half years of use. Some of the rails were very old, but the fish-plates, which were not fully tight, showed bright patches of metal at places of contact with rail. On replacing plate and re-bonding, the joint was equivalent to 39 inches of rail. Mr. Parshall.

A second rail, tested without fish-plate, showed also *no* deterioration of the bonding.

Some 66½-lb. rail laid on another line recently bonded, showed joint resistances equivalent to 9½ inches to 28 inches in four different cases.

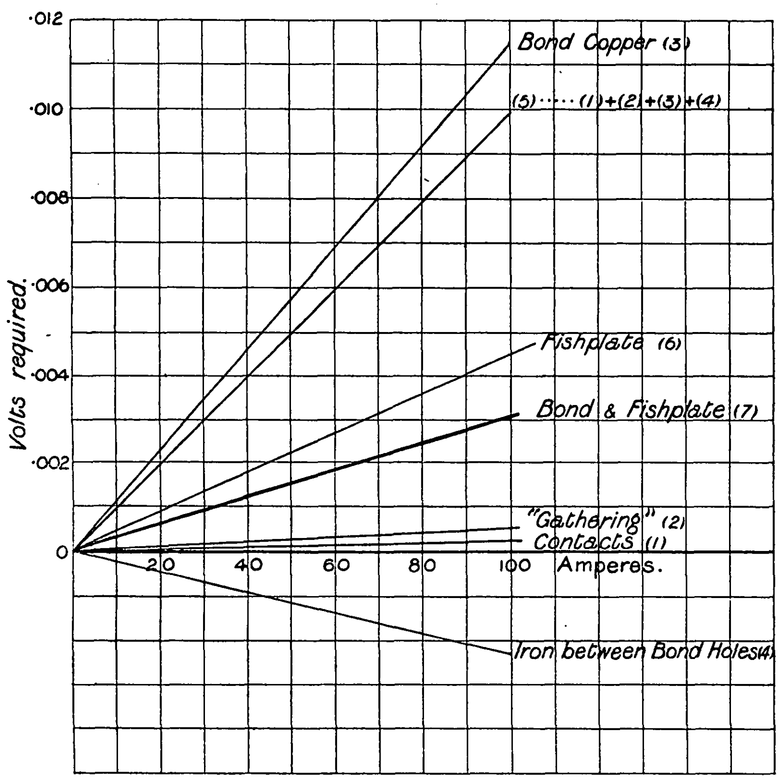

FIG. 2.

Volts required by various elements of joint in 80-lb. rail bonded with a single 30-in. 0000 copper bond, with ⅞-in. terminal in $\frac{7}{16}$-in. web.

Mr. Parshall.

Plastic Bonds.

1½-inch hole in the cork receptacle between fish-plate and rail filled with plastic material.

—	Increased Resistance due to Joint.	Inches of Rail.	Increased Resistance of 176 Joints, or per Mile with 30-ft. Rails.
	Ohms.		
83-lb. rail bonded to one plate only; both plates separated by paper from rail ...	0·0000213	24	0·00375
Do., but bonded to both fish-plates; plates not very tight	0·0000126	14	0·00222
Do.; plates a little tighter	0·0000123	14	0·00217
Do.; plates very tight; brown paper still between plates and rails	0·0000117	13	0·00206
Do.; brown paper removed; plates tightened very hard up	0·0000083	9	0·00146

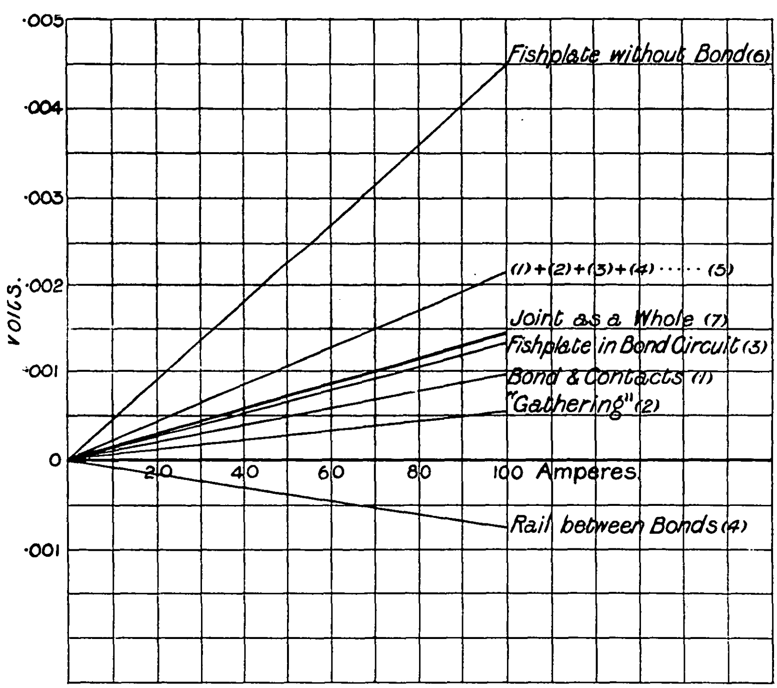

Fig. 3.

Volts required by various elements of joint in 80-lb. rail bonded with 1½-in. plastic bond to one fish-plate only.

From the above, it seems safe to take the resistance through fish-plates as equivalent to some extra 50 inches of rail, and to take this resistance as in parallel with the copper or plastic bonds used in addition. Curves can then be constructed for any particular system of bonding similar to those of Fig. 2, which gives P.D. for the various elements of a joint of 80-lb. rail bonded with a single 0000 B. & S. copper bond 30 inches long with 7/8-inch terminals. Mr. Parshall.

The contact and gathering resistances are added to the bond copper resistance, and the resistance of the iron between the bond holes deducted. This gives Curve No. 5. The resistance so found is taken as in parallel with the fish-plates' resistance and curve (7) calculated for the whole joint. The volts so found must be multiplied by the number of joints per mile, and added to the volts required to drive the current through a mile of jointless rail.

APPARATUS EMPLOYED IN TESTING.

All resistances were found by measuring the potential difference between two points on the rails when a constant current of 30–150 amperes was passed through the latter. A standard resistance of 0·0000398 ohm was placed in the same circuit, and the fall of the potential across this compared with that across the two points on the rail. The places at which current was led in and out of the rail were always at some distance from the points between which the potential difference was taken. Where measurements were made upon the actual track, current was supplied from an accumulator placed upon a car brought up to the spot. Current was led from this to a point in the middle of the rail to be tested, and was led out some 5 or 6 feet on the other side of a rail joint. The fall of potential was then measured between two points inside those by which the current was led into the rail, and also between two points on the same rail outside the places at which current was led into it. The standard resistance was included in the circuit, and comparisons taken with this at each stage. From these two measurements the resistance of the rail could be calculated as long as no cross

Mr. Parshall. bonds occurred upon the part of the track actually under test. To measure the resistance of the joints, a joint was included between the two points between which the potential difference was taken; and this was compared with the potential difference between two points at a similar distance apart on the continuous rail. It was found extremely important in some cases to reverse the current both in the rail and the potentiometer, since with the small potential difference measured, thermo-electric effects were very liable to disturb the results.

In certain experiments a current was passed into the rails at one end of the track, and taken out at the other. The current in the rails at intermediate points could be measured by taking the difference of potential between two points on the same metals which had been tested for resistance as above This had, of course, to be done for all four lines of the double track. The volts used to drive current through the whole length of track were measured by making use of the test wires. The potentiometer was employed for this purpose also, and the results may be taken as correct, within the limits of correctness of calibration of the instrument itself, which was supplied by Elliott Brothers.

NOTES ON ELECTRIC TRAMWAYS.

By Major P. CARDEW, R.E., and A. P. TROTTER, Members.

Major Cardew. The accompanying note, on return feeders for electric Tramways has been forwarded to me by Mr. A. P. Trotter; and, as it contains a neat graphical method for determining the fall of potential in the return with uniform distribution of current, and the proper points of application of return feeders, I think it may prove interesting in connection with Mr. Parshall's paper.

As Mr. Trotter alludes to previous suggestions of my own on this subject, I also forward a note which was prepared by me in May, 1894, and sent to the South Staffordshire Tramways Co., advocating the automatic regulation of this fall of potential.

P. CARDEW.