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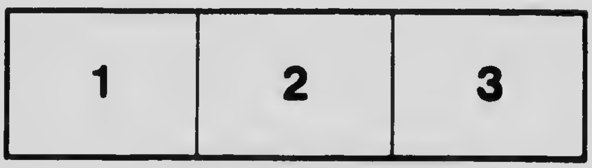
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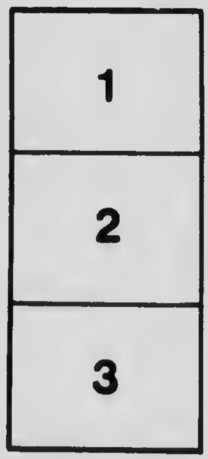
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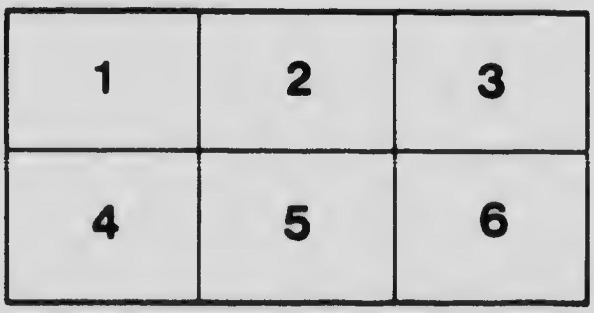
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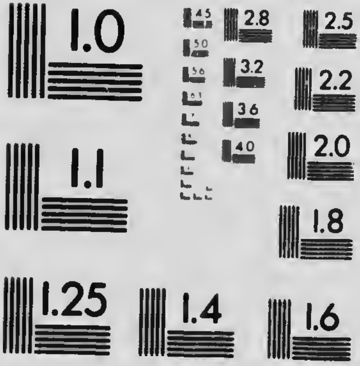

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Grounded Electric Transmission and Electrolytic Corrosion

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PREFACE.

The information given in the following pages, though by no means perfect, may prove serviceable to those who, like the author, have, at times, to consider the problems which arise as a result of the use of grounded transmission. If they do prove serviceable to a few, the author's object will have been accomplished.

THE AUTHOR.

Toronto, April, 1909.

Grounded Electric Transmission and Electrolytic Corrosion

I.

PRELIMINARY.

Even written in the briefest manner, a history of the use of the earth and grounded metallic substances as portions of the mediums whereby engineers have carried out practical electrical transmission would almost read like a romance.

First among the engineers to so use the earth were the telegraphists, prominently represented by Mr. W. H. Preece (now Sir William H. Preece), who, up to or about 1899, was for many years engineer-in-chief and electrician to the British post office. It can be easily understood that in such a position and controlling the telegraphs of that country (which are operated by the government) the British authorities were more inclined to make regulations to suit the electrical requirements of Mr. Preece's department than to suit the electrical requirements of the general public; so that, in the eighties, they formulated rather strict regulations to govern the use of grounded returns. Thus it was that electric traction was much delayed in the British Isles; the public of which country, when they finally awoke to the fact that their traction facilities were much behind those of some other countries (such as the United States of America), brought pressure to bear on their parliamentary bodies to again take up this question with the view to make the regulations less restrictive. A joint committee of the House of Lords and Commons was, therefore, appointed in 1893, with the result that a considerable amount of evidence was taken before it and published in one of the blue-books under the title "Electric Powers (Protective Clauses)." A short abstract of such evidence, from an electrolytic corrosive point of view, is as follows:—

ELECTRIC POWERS (PROTECTIVE CLAUSES)—BRITISH.

Sir Courtney Boyle—The government should, in drawing up regulations, consider the telegraphs first. Referred the committee to Major Cardew.

Mr. W. H. Preece—Had been on the lookout for electrolytic corrosion but, up to the time of his evidence, had been unable to find such. Referred the committee to Major Cardew, who decided that the judicious connection of pipes to rails would prevent detrimental action.

N.B.—Sir William and Major Cardew have, during the past few years, acted jointly as consulting engineers in connection with the installation of single trolley systems in England.

Dr. John Hopkinson—Was pretty common observation, both in England and the United States of America, that pipes became oxidized and had holes eaten in them

N.B.—Dr. John, for some time previously to his deplorable loss with other members of his family during one of his Alpine excursions, acted as consulting engineer (engineer) to the Liverpool tramways committee during the construction of the first portion of their electrical traction system. Sir Arthur Forward, who, up to the time of his death (about the same time as Dr. John's) was the chairman of this tramways committee, was one of the members of the joint committee.

Lord Kelvin—Grounded returns were a serious menace to pipe systems. It was useless for any one to come in to protect the Glasgow corporation's pipes from their own street railway system.

N.B.—Glasgow uses the single trolley.

Mr. G. E. Fletcher (L. & N. W. Railway)—Grounded returns resulted in detrimental action. Such could be avoided by connecting the pipes to the rails. Trouble would, anyway, result at bad pipe joints.

Mr. C. H. Morse (Boston, Mass.)—A report by him on conditions in Boston submitted—track returns in Boston were in a bad state; and that a considerable loss of power to the company and damage to the pipe resulted, but that such was preventable.

Mr. C. E. Spagnoletti (G. W. Railway)—Non-committal; and his evidence, in the main, of a chemical nature.

Mr. James Swinburne—Electrolytic action, as a result of grounded returns, by no means necessary. Favored connections between pipes and rails. Electrolysis more serious to companies operating traction systems than to companies operating pipe systems.

Mr. R. E. B. Crompton—Considered electroytic corrosion, as a result of thorough investigations made in London, a negligible factor. That the action of certain soils in London was much greater than the action due to electrolysis.

N.B.—London soil is mostly marl.

Major Cardew (Board of Trade)—Electrolytic damage could be avoided by ordinary care. Proper precautions taken at the outset and proper tests made afterward would prevent appreciable damage to pipes. Regulations could be drawn up which would make the use of grounded returns safe

Sir Frederick Bramwell (recalled)—Only way to prevent damage was by insulating both conductors.

N.B.—In 1897, his partner, when before the Liverpool tramways committee, stated that their firm had a knowledge of electrical traction work—had advised, from England, a New Zealand concern in connection with the construction of one mile of road. Their traction work, since such evidence, has been in connection with conduit systems, somewhat similar to the one in use by the surface roads of New York.

Professor Dewar—Having no knowledge of applied electricity, was inclined to take the same views as Sir Frederick Bramwell and Dr. John Hopkinson. His evidence, in so far as the question at large was concerned, was of a chemical nature—that corrosion of pipes depended, largely, on the chemical composition and the chemical constituents of the contiguous soil.

To those who have perused the voluminous amount of matter contained in the before-mentioned blue-book, the foregoing will appear very short. Such is, however, the result of much work; being an abstract of a longer abstract of a still longer abstract of the abstracted complete portions of all the evidence bearing on electrolytic corrosion which was taken.

GENERAL.

The second body of engineers to so use the earth were the telephonists; the bitter fight between whom and the opposing traction interests (based, principally, on the fact of inductive disturbances) is too well remembered to require much comment. It is sufficient to say, therefore, that the Supreme Court of Ohio reversed the decision (unfavorable to the traction interests) of the superior court of Cincinnati; the final portion of the finding of which Supreme Court was: "We are of the opinion that there has been no invasion of the rights of the telegraph association by the plaintiff in error, and that the telegraph association is not entitled to the relief prayed for in its petitiion. The judgment, therefore, of the superior court at general and special term must be reversed and the original petition dismissed. Judgment accordingly." It is assumed that the decision so reached was not based so much on the fact that each and every person has an equal right to use the earth as on two other facts:

first, that a really efficient system of telephone communication can only be obtained by the use of metallic circuits; while, second and "pro bono publico" (the lowest capitalization per mile and, thereby, the greatest distance which a passenger can be hauled for a given sum), the single-trolley system is the most suitable one for general electrical traction purposes. For which reason, it can be taken for granted that no amount of evidence taken in respect to the much debated question of electrolytic corrosion would lead, finally, to "lex scripta" which would prohibit street railways from using the single-trolley system. At the same time, it ought to be remembered that a favorable verdict on account of traction interests will only, on account of "lex non-scripta" permit such interests to operate with grounded returns which are installed and maintained on the most modern and approved engineering basis. This because no one corporation has the right by neglecting to maintain its plant in the proper condition to incidentally make abnormal use of the plant of other corporations and, thereby, accidentally cause a questionable amount of damage to such other plant.

The phrase "questionable amount of damage" is used because no really independent investigator would (because he could not) ever undertake to definitely state, even approximately, what the d mage caused by earthed track returns to other earthed conductors (pipes, etc.) really amounts to: while those experts who rely on the remuneration received from either one or the other side generally feel that they must work in unison with the other sailors on the ship which is carrying them. For the sailor who is independent enough to question a captain's orders will soon find that the command is given that he must be placed in durance vile or marooned on a desert island.

ELECTROLYTIC CORROSION—LITERATURE.

While much incidental literature has been written on the question of electrolytic corrosion, it does appear as if no one has had the courage to publish in some convenient shape any work dealing, in an approximately complete way, with this subject; for which reason it may not be out of place to give a short abstract of some of the literature already published, arranged in tabulated form herewith.*

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*It may be said that since the first publication of this history in 1904, a book has been published by Professor Sever. Mr. Waterman, who handled the office end in New York of the work undertaken by Mr. Richmond in the famous Richmond investigations, collaborated with Professor Sever when writing this book. In the courts, the street railway of Richmond won the case and the City of Richmond, which retained Mr. Maury, lost.

Investigator.	Locality	Date.	Publication	Remarks.
Adams		January, 1900	Municipal Engineer	Cause and Remedy
Barrett	Brooklyn, N.Y.	Jan. 18, 1895	Railroad Gazette	Report to commissioners of electrical subway
"	"	Jan. 26, 1895	Street Railway Gazette	Report to commissioners of electrical subway
"	"	Feb. 23, 1895	Engineering Record	Report to commissioners of electrical subway
Bridgden	Battle Creek	April 15, 1900	Engineering Record	Injury—Map
"	"	vol. 8, No. 6, 613	Cassier's	Protecting pipes
"	"	vol. 5, No. 12, 739	Street Railway Review	Potential readings
Brown	Newark, N.J.	Dec. 15, 1895	Street Railway Review	Prevention
"	"	October 14, 1897	Electrical Engineer	American and European practice
"	"	March, 1899	Domestic Engineer	Testing and protection
Brownell		June, 1900	N. E. W. Works Association.	Illustrated discussions
"		April, 1895	Cassier's	Legal aspect
"		April 6, 1895	Street Railway Gazette	Legal aspect
City Engineers	Boston	April, 1893	Report	Showing injury
Chamen	Glasgow, Scotland	June 7, 1898	Journal Gas Light	Report
Committee		Sept. 1, 1894	Am. W. Works Association.	Preventive measures
Davis	American Cities	Dec. 1899	Municipal Engineer	Conditions in cen. state
Dayton	Dayton			Trial—Evidence
Expert Engineer	St. John, N.B.	Jan. 4, 1894	Engineering News	Pipe breakage
"	"	March 29, 1894	" "	Broken returns
"	"	Jan. 26, 1899	" "	Abstracts of report
"	Jersey City	Feb. 2, 1899	" "	Abstract Knudson's report
"	Cambridge, Mass.	Oct. 14, 1893	Engineering Record	Increased bonding
"	Milwaukee, Wis.	Oct. 14, 1893	" "	Pipe-rail connections
"	Jersey City	Feb. 11, 1899	" "	Illustrated report
Farnham		April, 1894	Transactions A. I. E. E.	Paper
"		April 7, 1894	Engineering Record	Abstracts of paper

Investigator.	Locality.	Date.	Publication.	Remarks.
Farnham		April 21, 1894	Street Railway Gazette	Abstracts of paper
"		April 25, 1894	Electrical Engineer	" "
"		May 3, 1894, etc.	Engineering News	Corrosion of pipes conclusively shown
"		May 11, 1894	Railroad Gazette	Corrosion of pipes conclusively shown
"		May 25, 26, 1894	Engineering Record	Corrosion of pipes conclusively shown
Gray		Jan. 3, 1896	Electrical Review, London	Re work of Smith, Jenkins, Brown and Wilkinson
Herrick		June, 1898	Engineering Magazine	General treatment
"		May 5, 1900	Street Railway Journal	Paper N. E. Society
Hewitt		July, 1896	Journal Franklin Institute	General treatment
Hoopes		May 25, 1895	Electrical World	Prevention
Irving	Bristol, England	June 5, 1900	Journal Gas Light	Paper—Prevention
Jackson		Aug. 9, 1894	Engineering News	Criticisms of experiments
"		Aug. 11, 1894	Street Railway Gazette	" "
"		Aug. 17, 1894	Railroad Gazette	" "
"		September, 1894	Soc. of Assoc'd. Engineers	" "
"		Dec. 5, 1896	Electrical World	Details of experiments
Jenkins		May 15, 1900	Street Railway Review	Paper—Prevention
Keithley		September, 1894	Street Railway Review	Rail returns
Kelsey	Salt Lake City	Oct. 16, 1894	Engineering Record	Paper—Amer. W. Works Assn.
"	New York City	October, 1898	Transactions A. I. E. E.	Paper
"	"	Nov. 1898	Transactions A. I. E. E.	Discussion
"		March, 1900	American Electrician	Joint resistance
Knudson	Providence	August 4, 1900	Engineering Record	Corrosion pipe interiors
Low		February, 1895	Transactions A. I. E. E.	Prevention, bonding
Morse		March, 1893	N. E. W. Works Association	Cause and remedy

Investigator.	Locality.	Date.	Publication.	Remarks.
Morse		July 19, 1900	Am. W. Works Association.	Paper abstract
"		May 19, 1900	Engineering Record	Railway companies responsible
Maury	Richmond, Va.,	July, 1903		Report
Newbaker		February, 1900	American Electrician	General treatment
Perry		Sept. 15, 1894	Street Railway Gazette	Series method
Peoria	Peoria			Tria' –Evidence
Quincke		April 27, 1895	Ztsch. Ver. Ing.	Paper—Society of Engineers
Richmond Tn. Council	Richmond, Va.,	Feb. 27, 1896	Engineering News	Ordinance–1, 23, 9
" "		August, 1904	Minutes	W. Works Committee
Richmond	New York City	February, 1903	Reports	Manhattan Railway Company.
"	Richmond, Va.,	February, 1903	Reports	Investments, improvements
"	New York City	July, 1904	Report, Subway	Action unlikely
"		Oct. 8, 15, 1904	Electrical Review	Earth voltages
"		Nov., etc., 1904	Electrical Review	General tests, etc.
Rowland		May, 1897	American Electrician	Planning returns
Schoen	Richmond, Va.,		Report	Corrosion Evidence
Sever	Long Island			
Sheldon	Brooklyn, N.Y.,	May, 1900	Transactions A. I. E. E.	Cast-iron immune
Stewart	St. Joseph, M.,	July 7, 1894	Street Railway Gazette	Corrosive action
Stone and Forbes	Boston	September, 1894	N. E. W. Works Association	General treatment
" "	"	June 23, 1894	Engineering Record	General treatment
" "	"		Brit. I. Gas. Eng.	General
Storrs		vol. 10, No. 1, 33	N. E. W. Works Association	Paper—General
Swinburne		August 30, 1902	Electrical Review	Abstract of above
Whynkop	Brooklyn, N.Y.,	January, 1900	Popular Science Monthly	Cause—Prevention
"	"	April 29, 1900	Electrical World	Paper—Engineers' Club, Brooklyn

II.

Earth Voltage and Potential Measurements

ZEROS.

It is necessary for convenience to sometimes use in the consideration of electrical phenomena, besides absolute and arbitrary zeros, two others designated self-zero and medial zero; self-zero being that of the voltage of the point having the lowest voltage and medial zero that of the voltage of the middle point electrically in a generating and transmission medium.

Fig. 1.

Fig. 1 is a diagrammatic representation of a so-called insulated transmission medium. In practice, however, such insulation is not obtainable; for at some point or other of the circuit a lesser or greater ground exists. And it is due to the fact that such ground with direct-current transmission is one day at one point and another day at another point that the expression arose that "one day our system is positive and another day it is negative." It must be understood, of course, whether the system is running "negative" or "positive" that the direction of transmission remains the same.

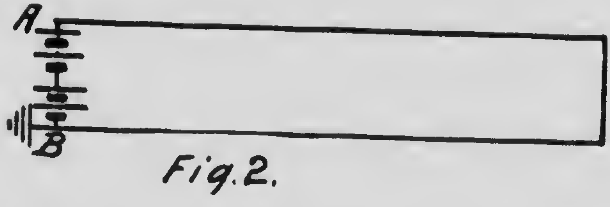


Fig. 2.

Fig. 2 similarly represents a generating and transmission medium, but with the low voltage side of the generating medium grounded. As a result, the voltage conditions can

Fig. 3.

be illustrated as shown in Fig. 3, in which BE being the zero line E is the voltage of the pole B, A is the voltage of the pole A, and AE is the varying voltage of the transmission medium. The arbitrary zero and the self-zero of this circuit will be that of the voltage of the pole B.

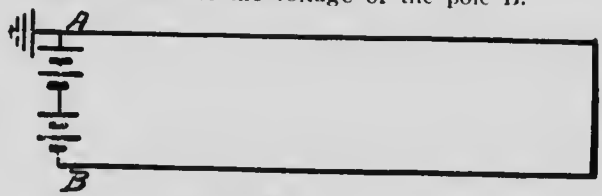


Fig. 4.

Fig. 4 illustrates, diagrammatically, similar apparatus; A being grounded instead of B, when the voltage condi-

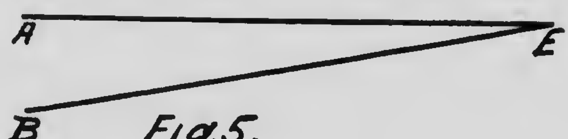


Fig. 5.

tions will have to be represented as in Fig. 5: in which AE being the zero line E is the voltage of the pole A, B is the voltage of the pole B, and BE the varying voltage of the transmission medium. The arbitrary zero of this circuit will be that of the voltage of A; while the self-zero will be that of the voltage of B.

Fig. 6.

Fig. 6 also diagrammatically illustrates similar apparatus, but with C (the medial point electrically between the two poles) earthed, when the voltage conditions will have

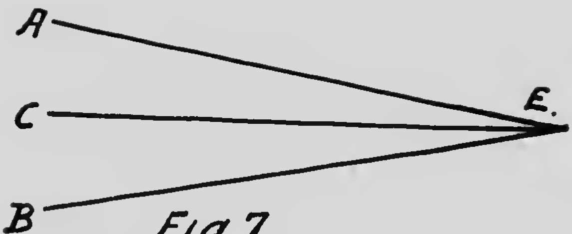


Fig. 7.

to be represented as in Fig. 7; in which CE being the zero line A is the voltage of the pole A; B is the voltage of the pole B; AE is the varying voltage of one-half of the transmission medium and BE the varying voltage of the other half of it. The arbitrary zero and the medial zero, in this case, will be that of the voltage of C; while the self-zero will be that of the voltage of B.

CENTRE-ZERO POTENTIAL METERS.

The author has defined electrical condition as the abnormal position of the molecules of which matter is composed. Voltage, therefore, may be described as the degree of such abnormal position, and must not be confused with potential, which is the ability to do work due to the difference between two voltages. Potential and not voltage, therefore, is the "cause" producing any "effect" designated an electrical phenomenon.

Incidentally, it may be stated that a so-called voltmeter is incorrectly termed. Correctly speaking, it should be termed a potential meter. For it does not measure voltage in respect to a standard zero but only the difference in voltage between (or potential of) two points, the one on one body and the other on another body, or between two different points of one body.

To illustrate, in a minor way, the practical application of the zero question, take the case of special potential meters designed by the author for the measurement of earth potentials.

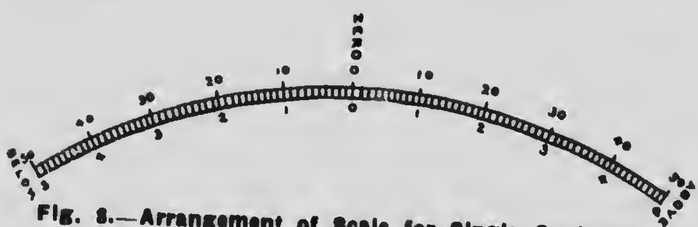


Fig. 8.—Arrangement of Scale for Single Centre-Zero Potential Meter.

Fig. 8 is a sketch showing the arrangement of the scale for a single centre-zero potential meter having two ranges of five and fifty volts, respectively. As will be noticed, the words "Above" and "Below" are used instead of the usual signs + and —, and that the centre of the scale is marked "Zero." The binding-post, usually marked + on a centre-zero instrument, is, in this case, marked "Zero." To take, with such meters, the potentials between the rails of a surface street railway and the hydrants with a view to tabulating the voltages of the hydrants, the modus operandi is as follows.

SINGLE POTENTIAL READINGS.

Each instrument, with two insulated cords, one long and the other short, is accompanied by two boys, the elder of whom handles the meter and hydrant connection while the younger one takes charge of the rail connection. The elder one is also provided with printed forms, a facsimile of which is marked Fig. 9, and is instructed to be very careful to

POTENTIALS BETWEEN HYDRANTS AND RAILS.
(FIGURES GIVEN ARE VOLTAGES OF THE HYDRANTS TO THE RAILS.)

Readings taken by ____________
Date ____________
Weather ____________
Preceding Weather ____________ *for* ______ *Days* ______

READING No.	LOCALITY	TIME	VOLTS	REMARKS.
		TO	TO	
		TO	TO	
		TO	TO	

Fig. 9.—Printed Form for Records of Potential Tests.

keep his end of the longer cord always attached to the "Zero" post of the meter throughout the whole set of readings while the younger boy holds the other end of it on to the near-by rail, which he has previously cleaned. The shorter cord, which is attached to one of the two other binding-posts (according to which of the two ranges is being used), is connected to the hydrant by the elder boy who is instructed to read the deflections just the same as he would the variations of temperature indicated by a thermometer; this is, if the deflection of the needle is above the zero, the reading is entered on his form without any sign; and, if the deflection of the needle is below the zero, the reading is entered with the sign — before it. If the deflections of the needle are both below and above the zero at the same place they are entered (to use arbitrary figures) as — 2.50 to 3.25. To assist in the prevention of mistakes, it should be impressed on the reader that he should always read and enter from a lower reading to a higher reading.

TWO SIMULTANEOUS POTENTIAL READINGS.

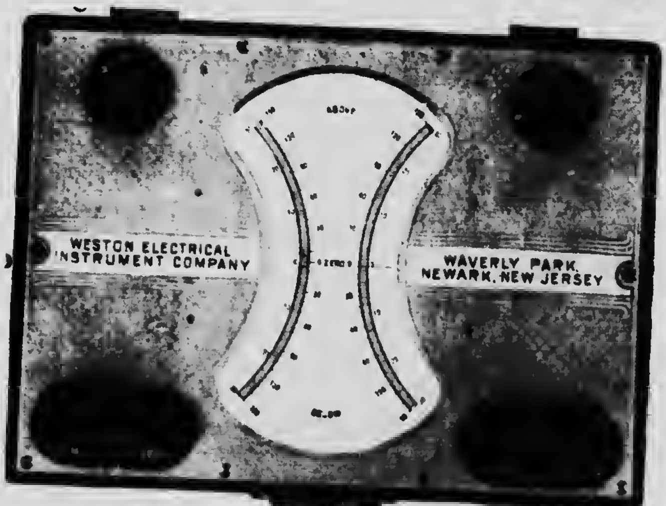


Fig. 10.—Duplex Potential Meter.

Fig. 10 is a reproduction of a photograph of a duplex potential meter (two instruments like that before described, but with the scales graduated for millivolt readings), also designed by the author. The lid was removed while the photograph was being taken so that the special arrangements would show up better. Duplex potential meters, similarly constructed, are used for comparative work—comparison of the voltages of two bodies with that of the voltage of a third one used as the zero. Take the case when investigations are taking place in regard to a surface road, an elevated road and cable sheaths (all earthed). First:—The surface road rails can be connected to the two zero posits while the other post of each side of the instrument is connected, respectively, to the elevated structure and the cable sheaths. Second:—A set of readings can then be taken with the zero posts attached to the elevated structural work while one of the posts on each side of the instrument is connected, respectively, to the rails and sheaths. The wiring of these duplex instruments is such that the needles move in similar directions and equally under similar influencing conditions. The comparative results are very interesting and instructive

Such explanations are rather long; but in practice it is remarkable with what rapidity and accuracy boys can take these readings, even if they have no electrical knowledge.

ILLUSTRATION.

As a practical illustration of the foregoing method of taking potential readings and the method of analysis afterward adopted, take the case of one investigation made by the writer in a district where of two systems (one an elevated and the other an overhead trolley) only the trolley was being electrically operated. Investigations were carried out in reference to two conditions of operation, which two conditions are diagrammatically represented, the one in Fig. 11 and the other in Fig. 12. When the street rails had no load on them for some distance away from the elevated structural ironwork (this is, when the nearest carload was as in Fig. 11)

Fig. 11.—Street Rails with Load Some Distance from Structural Ironwork.

the structural ironwork was about five volts above the voltage of the street rails in proximity to it; or, vice versa, the street rails were about five volts below the voltage of the adjacent structural ironwork. The grounded portions of the two systems at this point had, therefore, a potential of five volts When the carload was on the street rails close by the structural ironwork, however, as shown in Fig. 12, the

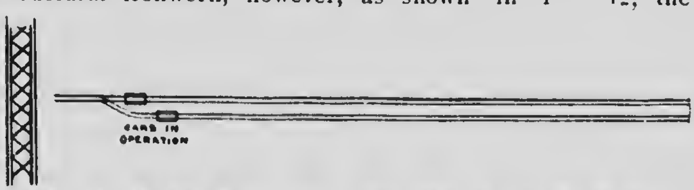


Fig. 12.—Street Rails with Load near to the Structural Ironwork.

structural ironwork was only about one volt above the voltage of the contiguous street rails; or, vice versa, the street rails were then about one volt below the voltage of the structural ironwork. The grounded portions of the two systems, therefore, had, under this changed condition of carload, a potential of only one volt. The lesser potential at this point indicated, therefore, the transmission of a much greater amount of energy by the grounded return of the street railway system than was indicated by the higher potential, which is explainable. For the voltage of the trolley wire of the street railway system was several hundred volts above the voltage of the street rails; and when a considerable amount of energy was being transmitted from the trolley wire through the cars to the street rails, the latter, as a result, were raised in voltage; this is, the voltage of the street rails near the structural ironwork were raised from — 5 to — 1. The zero which was used in this case—an assumed one—was that of the voltage of the structural ironwork at the point where the investigations were carried out.

Several cases have also come under the writer's observation where of the two returns (during operation) the street rails had the higher voltage. As a result, the partial balancing, equalizing or reversing of the comparative voltages of the elevated structural work and the street rails appeared to result when the elevated trains were passing, so that the potential nearly always increased as the distance of the elevated trains from the point of investigation increased. Care has to be exercised, therefore, in concluding, in such a case, that a gradually increasing potential is due to the gradual cutting out of resistances by the elevated motorman at the controller: this is, an increasing potential between elevated structural work and street rails is due, in such case, to a decreasing elevated load at the point of measurement.

INTERPRETATION OF POTENTIAL READINGS.

When potential readings are taken, care should be used that the deflections of the needle of the potential meter (voltmeter) do not mislead one, due either to imperfect connections at the terminal leads or through the failure to fully consider the $C = \frac{I}{R}$ law analytically.

As an example of imperfect connections, take the case of a poor conductor or insulating material, such as a cement pavement. Naturally enough, if the terminal leads are simply laid on the cement at two different points, the contacts made are bad ones. To make good connections in a case like this, a liberal amount of water should be poured on the cement at the points between which the readings are to be taken. Then two tin pails, weighted with water and with the terminal leads attached to them, should be placed on these watered points, one pail on one point and the other pail on the other point.

As explanatory of an analytical consideration of the $C = \frac{I}{R}$ law, take the case of the complaint made to the author by a railway company that the men handling the installation of its bare cables, intended as auxiliaries to its third rail which was in service at the time, were receiving severe shocks.

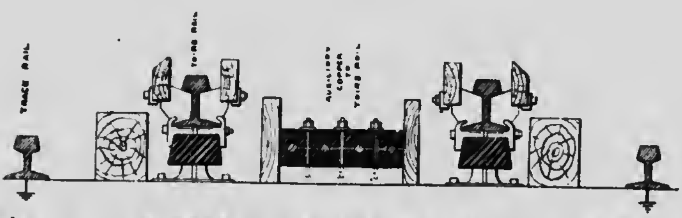


Fig. 13.—Arrangement of Bare Auxiliaries, Third Rails and Traction Rails—One Rail of Each Track.

Fig. 13 is a sketch illustrating in cross-section the arrangement of the bare auxiliaries and third and traction rails.

On examination, it was found that the inconvenience to the men only resulted when these bare cables were insulated (not grounded). A thorough investigation gave the following results:—

Contact, by means of the hands to these bare cables and the traction rails, did, at times, cause unpleasant sensations of such magnitude as to be conclusive to one experienced to such that a considerable potential, much greater than that shown by a potential meter, existed.

The sensations were only experienced by making and breaking contact. They were, therefore, not due to alternating potential.

As the sensations were not due to alternating potential, they were not the result of induction caused by the few volt variations of the voltage of the third rail.

As the shocks were rapidly experienced if making and breaking were carried out rapidly, such could not be due to the discharge of inductance (induced statical charge), as in the case of a so-called static condenser.

When readings were taken with a potential meter, the lineal deflections of the needle were the same whether the low or high range terminals of the instrument were used. Such unexpected action of the meter, however, is explainable. For voltage is only one of the factors necessary to produce a deflection of the needle, as it simply forces the amperage through the resistance. So that $C = \frac{I}{R}$ is only true when the amount of C is sufficient. In Fig. 14, consider

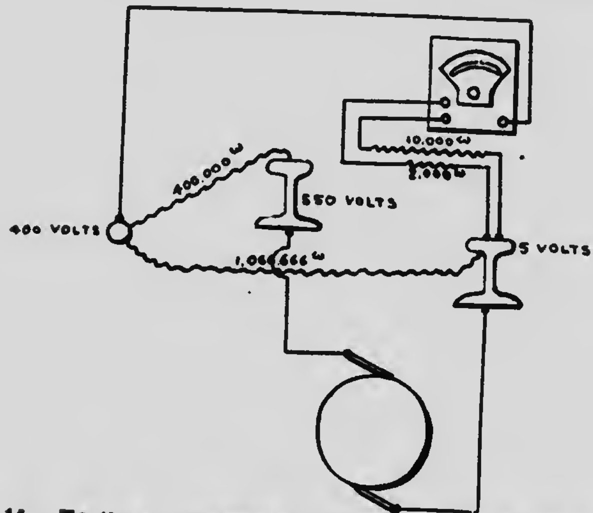


Fig. 14.—Testing Arrangement giving Misleading Readings due to High Insulation Resistance in Series in Test Circuit.

the meter as having two ranges: the resistance coil of the lower one having with the resistance coil of the movable coil a resistance of 2,000 ohms; and the higher range having, similarly, a resistance of 10,000 ohms. That the voltage of the third rail is 555. That the traction rails have a voltage of five, due to a return drop of five volts. That the insulation resistance between the third rail and the bare auxiliaries is four-tenths of a megohm. That the insulation resistance between the bare auxiliaries and the traction rails is a little over one megohm. That, of course, the third and traction rails are connected to a generating medium. The voltage of the bare auxiliaries will then be 400.

Now, by $C = \frac{I}{R}$, the 2,000-ohm resistance requires for a true deflection $\frac{400}{2,000} = \frac{200}{1,000}$ amperes, or 200 milliamperes.

But, when the meter is connected to the bare cables and the traction rails, the total resistance controlling the C is 2,000 + 400,000 ohms; which, by $C = \frac{I}{R}$, permits of the transmission of only $\frac{400}{402,000} = \frac{1}{1,005}$ amperes, or, roughly, one milliampere. But it has been shown that 200 milliamperes are needed for a true deflection under the condition of potential existing. As a result, only one-two-hundredth of a true deflection will be obtained. This is, the meter instead of showing a potential of 400 on the lower range of the scale will only show one of 2.

Similarily, the 10,000-ohm resistance requires for a true deflection $\frac{400}{10,000} = \frac{40}{1,000}$ amperes, or 40 milliamperes. But the total resistance governing the amount of C transmitted is 10,000 + 400,000 ohms; which amount of C, therefore, is $\frac{400}{410,000} = \frac{1}{1,025}$ amperes, or, roughly, one milliampere. But, in this case, it was shown that forty milliamperes are required to produce a true deflection. As a result, only one-fortieth of a true deflection will be obtained. This is, the meter instead of showing a potential of 400 on the higher range of the scale will only show one of 10.

Now, two volts potential by the lower range and ten volts potential by the higher range are read by a deflection of the needle to the same point on the scale. This is, the lineal deflection of the needle of a potential meter, in cases similar to that under consideration, will always be the same whether the low or high range terminals are used. And in somewhat similar cases, where very small potentials are dealt with, as in many instances occur when taking the potential of earthed conductors, the deflections, owing to the small amount of C available, will be so slight as to be unreadable. Many cases have come under the writer's observation where, having obtained a potential of, say, one-quarter of a volt between one earthed conductor and an earthed return and two volts between another earthed conductor and the same return, he has been unable to obtain readings showing a potential between the two earthed conductors though as will be understood, there must have been a potential of one and three-quarters volts.

III.

Track Drops—Comparative Simultaneous Voltages of Different Points.

ELABORATE APPARATUS.

Track drops are losses in voltage along tracks and it is very necessary, not only to assist in making surveys, but also to keep check on the condition of the tracks from a conductivity point of view after they have once been placed in good order, that some arrangement should be made

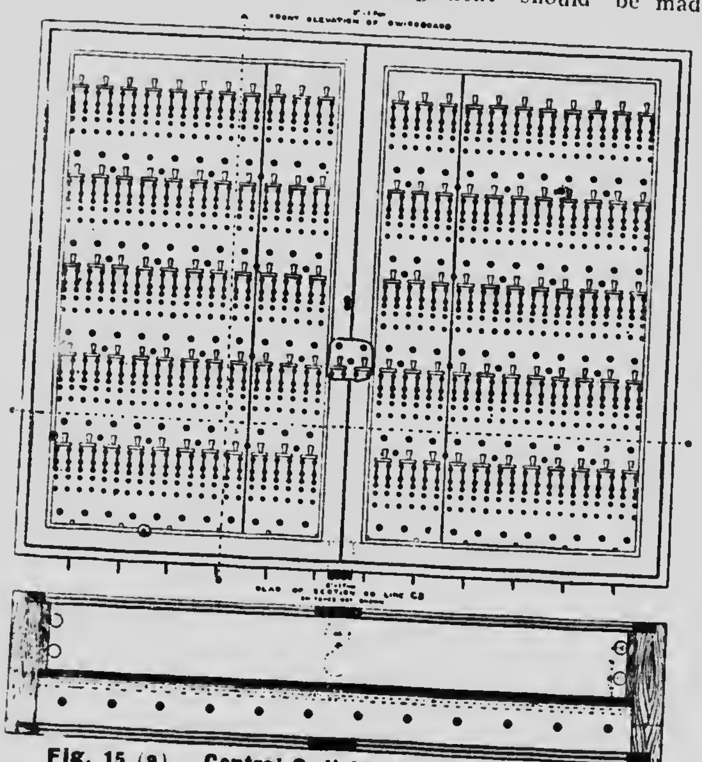


Fig. 15 (a).—Central Switchboard Testing System. Front Elevation and Sectional Plan.

whereby the voltages of different points of the low-voltage side of a system can be simultaneously taken at least once a month.

For this purpose, the author once designed a rather complete set of apparatus, consisting, in the main, of one special switchboard for the telephone central office and subsidiary apparatus for each point of the system chosen as suitable to know the voltage of.

Figs. 15 (a) and 15 (b) are reproductions of the drawings of such special board, which consists of a substantially made frame box with the back removable and two glass doors so hinged in front that they can be locked in the centre. The switchboard proper is built of three sheets of hard rubber fastened down around the edges, by countersunk flat-head brass screws, to an inner-projecting portion of the frame. On these sheets are mounted five rows of twenty-four double-

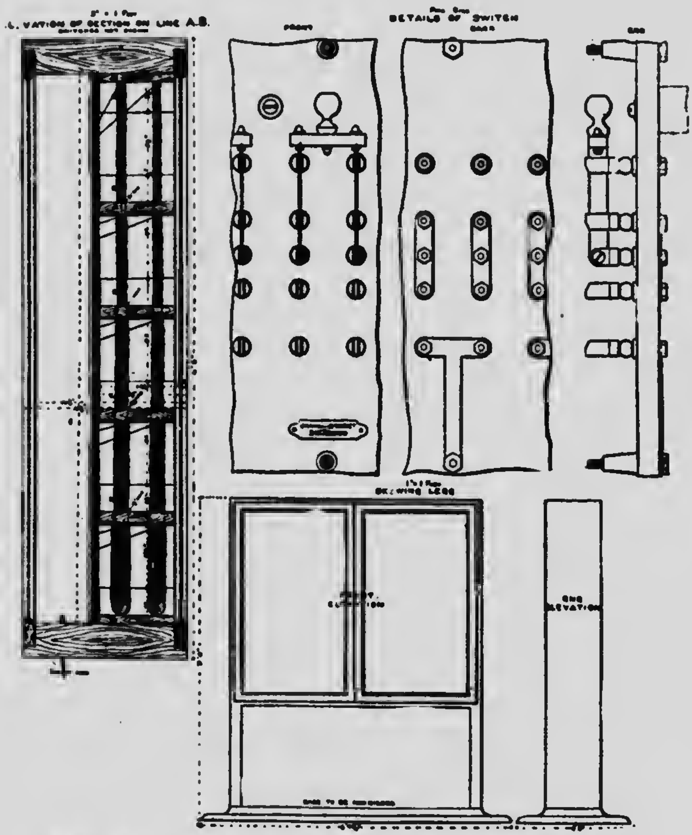


Fig. 15 (b).—Central Switchboard Testing System. Sectional Elevation and Details.

pole, double-throw switches with one plug below each switch. Through the bottom of the frame run twelve flexible cords, to the inner end of each of which is attached a small socket made to fit the plugs under each switch, and to the outer end of each of which is connected a suitable meter terminal. The wiring is on the back of the board (between the rubber sheets and the removable back), and consists of small rubber-covered wires formed and stitched on the principle similar to that adopted in telephone practice. One bunch of formed wires constitutes the incoming cable and the other bunch the outgoing cable.

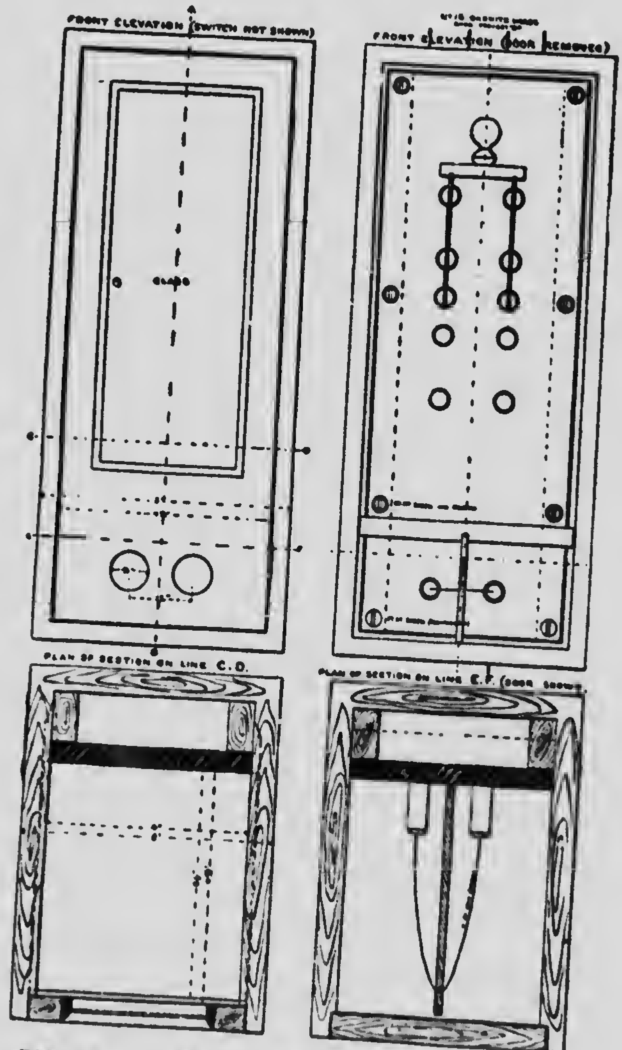


Fig. 16 (a).—Station Switch and Fuse Boxes. Testing System.

Figs. 16 (a and b) are drawings of the subsidiary apparatus. This consists of a small box, the upper part of which contains a sheet of hard rubber on which is mounted one double pole, double throw switch. One of these is placed alon side of each telephone located nearest to the point of the track of which a reading of the voltage is required.

To connect the special board up, the required telephone wires are cut between the distributing rack and the switchboard of the telephone exchange; and the ends from the distributing rack are connected to the incoming cable of the special board, while the ends from the telephone switchboard are connected to the outgoing cable of the special board. The two wires of each pair of the incoming cable are connected to the middle points of their particular switch to the upper points of which switch are connected the two wires of the corresponding pair in the outgoing cable. Each

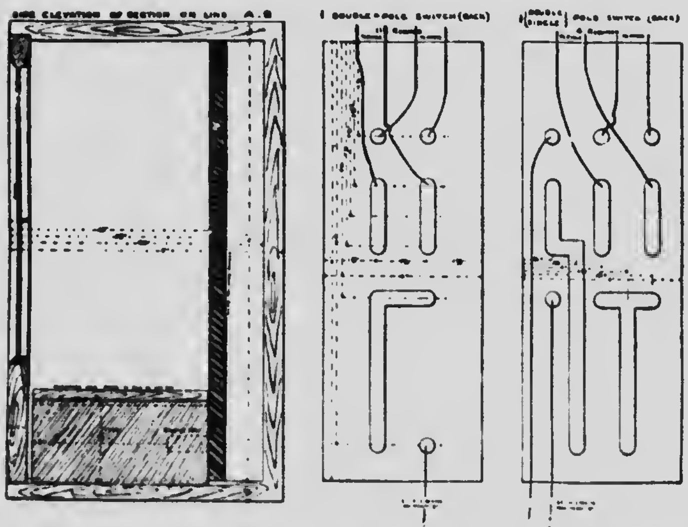


Fig. 16 (b).—Station Switch and Fuse Boxes, Testing System.

CONNECTING UP ELABORATE APPARATUS.

switch has its bottom points connected in multiple to the plug mounted below it. The details of the wiring and the other parts will be understood after examining the detail drawings in Fig. 15 (b). Thus, when all the switches are up, the telephone wires are in regular service; while, when down, each pair of wires will be in multiple with one of the small plugs and the telephone service cut out. To connect up the subsidiary apparatus, the line wires are cut at each point near the telephone and the line ends are then connected to the middle points of the switches, the upper points of which switches are connected to the line posts of the telephones. Each box has a lower compartment lined with asbestos and divided in the centre with a piece of leatheroid (fibre); and in each of the divisions so formed is mounted a binding-post with a fuse wire between them. In practice, the author has found that this fuse is not necessary but it is provided to allay the fears of telephone officials. The first binding-post in each box is connected by a wire or strip to the lower points of the switch, and the second one to the nearest track bond. If two connections (two points to take readings of) are required at any one of the stations, the second binding-post is connected to the middle point of a single-pole double-throw switch mounted alongside of the double-throw one, the top point of which is connected to the nearest track bond and the lower point to the other point desired.

TAKING SIMULTANEOUS READINGS.

To use the apparatus which has been described, the modus operandi is as follows: Eleven below-and-above-zero-reading potential-meters (Richmond pattern) are placed on a table near to the special board, and all the zero posts connected to one of the flexible cords at the bottom of the special board. The plug on the other end of this cord is forced on to the socket below the switch which is connected to the wires from the power-house telephone, and the switch of the subsidiary apparatus alongside this telephone has its lower points connected to the low-voltage bus-bars (negative bus) instead of to the nearest track bond. This power-house line, when the readings are being taken, becomes the zero wire. The other eleven cords, after their socket ends have been forced on the plugs belonging to the switches controlling the points at which voltage readings are desired, are connected one to each of the other binding-posts of the meters. The operator at central is then requested by the head reader to call up the twelve points (power-house first) and request them to throw their double-throw switches down, to stay by them for fifteen minutes and then throw them up again. When he has received favorable answers, he so notifies the head reader, who immediately throws down the corresponding twelve switches on the special board. Then, calling his eleven assistant readers to order and with watch in hand, he waits until the second hand reaches the minute, when in a clear, loud voice he says "Now," repeating the word every ten seconds for two or three minutes. Every time he says "Now," each assistant notes the deflection of his meter needle and jots such down consecutively on the sheet provided, which is ruled with spaced columns, ten spaces to each column. At each minute, the head reader says immediately after the word "Now" the word "Minute," by which the assistants know that the reading which they are entering must come in a space at the head of one of the columns. This, in case an assistant has skipped the entering of one reading, and so that all his readings thereby may not become valueless.

After the readings have been all taken, the head reader immediately throws up the twelve switches on the special board and notifies the operator at central that he has finished. The operator at central, after the fifteen minutes have elapsed, takes the trouble to call up the twelve points and find out whether the attendants at these points have or have not thrown up their switches as requested. In case of any special emergency, any one of the attendants at any one of the twelve points can obtain telephonic communication while the readings are being taken by throwing up his switch. This stops the deflection of the needle of the potential meter on his line, the assistant reader in charge of which instrument immediately throws up his switch, whereby central is called in the regular manner.

It is a distinct advantage to advise the attendants at the power-house as to the [illegible] during which these readings are to be taken, and to [illegible] request them to carefully take ammeter records of the [illegible]al output during this period.

SIMPLE APPARATUS.

This class of testing can be easily carried out by any company having a central exchange either of their own or rented from some local telephone company, provided that the instruments operated from it are located at suitable points of their system. Suitable outside telephone points having been chosen, a small doublepole, double-throw porcelain switch (obtainable from any dealer in electrical accessories) is installed near each telephone and connected up similar to the method before described. At the telephone central the telephone cable is cut and a box with the desired number of similar porcelain switches (about twelve, as a rule), installed in some convenient near-by position, is wired up similar to the manner which has been explained in regard to the special board.

Once the apparatus is installed, tests should be made at frequent intervals, care being taken that the readings are made at similar times of the day (approximately equal load conditions) on each occasion; and if the duties connected with such are controlled by some other department than the one in charge of the bond testing the general manager will find that the information obtained from the readings serve as a very effective check on the bond-test sheets turned in.

Fig. 16 (c) is a sketch diagrammatically illustrating this simpler method of making simultaneous drop tests in regard to eight outlying points. A is a formed and sewn telephone cable running to the office branch telephone exchange from the top terminals of C C, which consist of eight double-pole, double-throw porcelain knife switches mounted in a box. B is the incoming formed and sewn telephone cable, eight pairs of which are led to the middle terminals of C C. The two bottom terminals of each switch

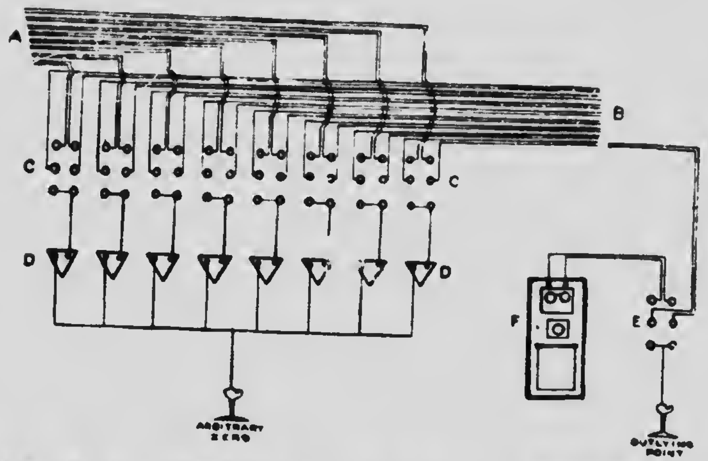


Fig. 16 (c).—Diagrammatic Illustration of Arrangement for making Eight or Less Simultaneous " Drop " Tests.

+ side of its voltmeter D. The zero (—) side of each voltmeter is connected to arbitrary zero (lowest voltage point of the rail system). E is a double-pole, double-throw porcelain switch to the middle points of which are attached the two incoming telephone wires. The two top points of this switch are connected up to the local telephone and the two bottom points to the nearest rail-bond.

Such simple and economical apparatus forms a means whereby these tests, which in the present state of electrical engineering are an absolute necessity, can be easily made at a minimum expenditure.

IV.

Stray Transmission Measurements

GENERAL.

About the most important of the many phases of grounded return investigations is the securing of data relative to the amount of accidental transmission by means of auxiliary earthed conductors, such as water-pipes, gas-pipes and cable sheaths; to obtain which several methods have been adopted. These can be roughly summed up under four headings, as follows:—

1. Amperes calculated from drops taken on two-foot lengths.
2. Amperes calculated from ampere and drop readings taken between distant points.
3. Amperes measured between the ends of a break in the accidental conductor.
4. Amperes taken experimentally in connection with plant laid especially for such purpose.

TESTS.

First Method.

Of these four methods, the first is the most popular one; particularly with those corporations which are arranged on the opposite side to the traction interests. The apparatus required is a meter with fifteen and 150-millivolt ranges with its calibrated leads (preferably a duplex one, Richmond pattern; because such is useful in checking the Conant bond-tester used in another branch of the investigations); a medium-sized rough file; a two-foot rule; a cold chisel and a chipping (machinist's) hammer. To use the apparatus, excavations about four feet long and wide enough to allow ingress and egress to the reader are made at various points of such a depth as to completely uncover the pipe or other earthed conductor to be tested. In each hole excavated, the conductor is cleaned at two places about two feet apart by means of the chisel and hammer followed by the file. Points two feet apart are then accurately laid off on such cleaned surfaces with the rule and the drop taken between such with the meter. When all the drops are taken and by use of a prepared table of the resistances of two-foot lengths of different sized pipes or cable-sheaths, the C is calculated by $\frac{I}{R}$, where I = the reading obtained and R = the resistance of the two feet. This popular method, whereby the two feet of metal in each case becomes a temporary shunt, has been more or less fully described by Maury in vol I., No. 4, p. 74 of Engineering News. For this class of testing, however, the writer prefers to use both sides of the duplex instrument by laying off two two-foot distances (three points), only accepting as true those duplex readings which simultaneously agree. This, because he has found that duplex readings so taken on cable-sheaths have not often agreed. Whether such disagreement was due to the imperfect contacts made by the lead terminals or to the use of the cables for alternating transmission can not, however, be definitely stated at present.

Second Method.

The second method, and, as a rule, most satisfactory one, consists in taking the voltage between two points and then immediately short-circuiting them and taking the voltage and amperage. The apparatus required is a light wagon, a reel, about 500 feet of flexible rubber-covered No. 6 B. & S. wire, the same length of electric light cord, a duplex instrument (ammeter and voltmeter), two single-pole double-throw switches and four heavy iron clamps. About 475 feet each of the wire and the cord (which should have an inner insulation of rubber) are bound together at points about twelve inches apart by means of insulating tape and wound on the reel which is mounted between two upright castings similar to those which will be described in another article. On one of the flanges of the reel and around but insulated from the axle is secured a circular brass ring which makes contact with a brush so held by a brush-holder attached to but insulated from the frame that the brush will make good contact whether the reel is revolving in one or the other direction. The inner end of the cord is threaded through a hole bored in the flange, projecting a few inches beyond its edge. The outside ends of both the wire and the cord are connected in multiple to the bodies of two of the clamps by means of roundhead machine screws and copper burrs.

Contrary to the case when collecting data for the plotting of voltage contour lines (vide V.), a rough wagon of the type used by hucksters may be used for this class of testing and, as the tests made are not many in number, almost any sort of a heavy horse will suit all requirements.

Fig. 17 is a sketch showing diagrammatically the arrangement of the switches and instrument, in which A is the duplex instrument with " two " and " twenty " ranges. The left side, in connection with the two shunts B and C, is used as an ammeter; while the right side is used as a voltmeter D is a single-pole, double-throw switch, to the middle point of which is connected thirty feet of the heavy wire. E is a small single-pole, double-throw switch, to the middle point of which is connected thirty feet of the flexible cord. To the outer ends of both the wire and the cord are connected in multiple the other two iron clamps. The remainder of the wiring can be traced out without any description.

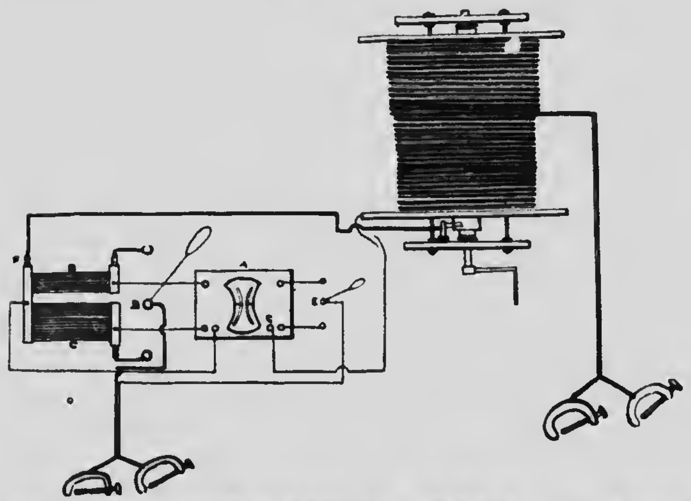


Fig. 17—Diagrammatic Sketch of Arrangement of Apparatus for Measuring Stray Transmission.

The two shunts, the two switches, the calibrated leads and the instrument should be obtained from the instrument makers all mounted on one base; and on no account ought the makers to be directed as to the details. The method of making shunt connections is a question for the instrument expert only.

To install the apparatus, the reel is placed in the rear end of the wagon and the instrument portion mounted on a smooth plank attached to the side of the wagon which is protected by a canvas covering stretched on a light framework. From F (Fig. 17) is run a piece of heavy wire to the brush-holder; and from the binding-post G of the meter is connected a small piece of flexible cord long enough to reach to the end of the cord projecting beyond the edge of the reel.

To use the apparatus, the wagon is taken to a hydrant and the clamps from the reel attached to it. The driver is then instructed to go ahead to the next hydrant, to which the clamps from the shunt are attached. Care should be used by one of the attendants that the reel does not "run away with itself" when the wagon is moving. Both switches are then thrown down. If the readings are so slight that the lower scales would be preferable, the switches are thrown up instead. When the proper scales have been selected, the ammeter switch is opened and the deflection of the voltmeter needle watched until satisfactory and steady. Then, remembering this deflection, the ammeter switch is quickly closed and both deflections at once noted. The three readings are then entered as voltage before short-circuiting and as voltage and amperage after short-circuiting. To facilitate the entering of the readings, the reader is supplied with sheets similar to those shown in Fig. 18.

READINGS BETWEEN HYDRANTS.

Readings taken by ________________

Date ________________

Weather ________________

Preceeding Weather ________ *for* ______ *Days* ______

READING NO.	LOCALITY.	TIME.	BEFORE SHORT-C'T	AFTER SHORT CIR'T		CALCU'D	REMARKS.
			VOLTS.	VOLTS.	AMPERES	AMPERES	
	TO	TO					
	TO	TO					

Fig. 18.—Printed Form for Entering of Readings.

The hands required for the operation of the apparatus, excepting, of course, the expert in general charge of the investigations, are a college or other student of electricity at $1.50 per day; a driver at the local rate of pay; two strong active linemen (helpers) at $1.50 a day; and one bright boy at 50 cents a day. The work and data obtained should be, in this case, for the legal department. The wagon and the hands should report at the office at 8 a.m. and immediately start for the scene of the day's operations. Lunch should be taken at noon and the wagon start for the stables at 5 p.m. The reader should then return to the office and enter on clean sheets the readings which have been taken together with the calculated results. These sheets should then be at once turned over to the legal department which, when considered necessary, will confer with the general manager.

The reader will find it a little difficult at first to remember correctly the three readings up to the time of entering them, but with a little practice the difficulty will be overcome. He can, too, and in time acquire the habit to take not only the steady deflections but also their maximum and minimum fluctuations. Such, however, is exceedingly trying and wears the reader out in quick order.

After the readings are taken at this point, the clamps are unloosened at the second hydrant and the wagon returns to the first one. While so returning the cable is rewound on the reel, and when the first hydrant is reached the other clamps are also unloosened. The performance is then repeated between the other hydrants.

The principal of this method is based, of course, on the $C = \frac{I}{R}$ law as applied to divided circuits. To calculate the C, the formula is $C = \left(\frac{V'}{V' - V''}\right) \times C'$ where V' = the voltage before short-circuiting and V'' and C' = the voltage and amperage, respectively, after short-circuiting; or, in plainer words, the transmission in amperes taking place by means of the pipes is equal to the amperage after short-circuiting multiplied by the quotient of the voltage before short-circuiting divided by the difference between the voltage before short-circuiting and the voltage after short-circuiting. Thus, if the three readings are 1.5 volts before short-circuiting, and 1 volt and 2 amperes after short-circuiting, the transmission is

$$\frac{1.5}{1.5 - 1} \times 2 = 6 \text{ amperes.}$$

Third Method.

The third method, while very accurate, can seldom be carried out, and, as it consists of simple ammeter reading, requires no description. It is used to measure the amperage returning by pipe and cable-sheath drainage coppers, that collected by ground plates and in a few other cases.

Fourth Method.

As a preliminary to a description of the fourth method, consider the diagrammatic illustration marked Fig. 19, in which AB represents the track rails, CD the line of pipe and EF a connection between the rails and the pipe. Now, if the resistance of the earth between the rails from G to B and the pipe from H to D plus the resistance of the pipe from F to D be high as compared with the resistance of the rails from E to B, the accidental transmission by means of the pipe will be a negligible factor. If, however, a heavy connection be made between B and D with an ammeter inserted the reading obtained will depend upon the load between A and I and the relative resistances of the rails and the pipe line. Such connections as EF and BD often exist through gate-boxes, pipe valves and rails being jammed together;

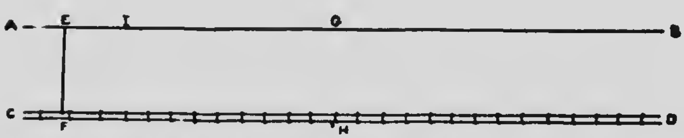


Fig. 19.—Diagrammatic Sketch of Relation of Track Rails and Line of Pipe.

or from accidental contacts between rails and service-pipes or cable-sheaths or bare auxiliary copper returns. That a connection such as EF exists is no reason that a connection should be made between B and D. For two wrongs do not make one right. In such a case, therefore, EF should be removed even if, for some special reasons, a connection is made at the power-house end between B and D. Apropos of which, the author is aware, of course, that a considerable amount of bonding has been installed—and still exists in certain districts—between the rail-returns of electrical traction systems and the earthed metal-work of other interests; but he has for many years strongly opposed the methods adopted to carry out this work and, as this is an important phase of the question at issue, some advice affecting it will be given in the last two chapters.

Having dealt with the preliminary, the fourth method, which has often been proposed by the author, but which up to the present time he has been unable to follow, may now be considered. Assume a portion of a straight piece of track forming the suburban or outer end of some line, as represented diagrammatically in Fig. 20, in which AB represents a trolley wire, connected while experiments are being made to a storage battery with an ammeter inserted near A; CD represents a track divided into insulated sections, as shown by the crosses; EF represents a pipe line deadended at both ends and also divided into sections by breaks, as shown by the crosses; and L, L^1, L^2, L^3, L^4, L^5 represent similar pieces of apparatus, each one supplying an equal load of, say, fifty amperes to the track. At each of the points designated by a cross a short length of insulated cable would have to be electrically connected to the metal work on each side of the cross; and on each free end of each cable a suitable lug would have to be sweated. By then bolting the lug faces together, the track and pipe sections, respectively, could be made continuous, or by inserting an ammeter between two lug faces readings could be taken. To use such apparatus the switch G would have to be closed and the ammeter inserted in the trolley wire be watched until it showed a steady

Fig. 20.—Diagrammatic Sketch of Relation of Trolley Wire, Track Rails, Pipe Line and Measuring Apparatus.

load. The ammeter readings would have to be taken at all the points marked with a cross. Voltmeter readings would also have to be taken between the tracks and the rails. Such tests, carried out first with the rails not bonded and then with the rails bonded, would give some very valuable data to assist in the consideration of the problems connected with electrolytic corrosion. The pipe line would, of course, have to be specially laid and covered up, except at the points marked with the crosses; but could, however, be laid with the intention to use it afterward as a water-main by making up the breaks after completion of the tests.

VALUE OF GROUND PLATES.

The author, like many others, has several times installed apparatus and made tests with a view to find out the values of earthed-plates as transmission mediums in connection with roads operated with grounded returns. Using (in Philadelphia about 1894) a large number of copper sheets buried in the ground near the low-voltage bus-bars and surrounded by charcoal, the connection between the plates and the bus-bars being made with a large number of 1,000,000-circular-mil cables, he was unable to obtain any deflection of the ammeter. Using (in Richmond, Va., about 1903) a plate with the surface of about 900 square feet on the bed of a river at a point about one-quarter of a mile from each of two power-houses, and with 500,000-circular-mil cables and connections between the plate and the low-voltage bus-bars of each, he found that the transmission between the plates and one power-house was about three-quarters of an ampere, and between the plate and the other power-house about one-quarter of an ampere; these with a load of about 2,500 amperes. H is also found that ironwork set in concrete forms a much better earth connection than ironwork set in soil when a connection is made through a resistance in each case between the ironwork and the trolley wire of a grounded system The probable reason for this is that the ironwork set in soil soon becomes coated with a thick incrustation of oxide, which forms a poor connection between the iron and the soil; while in the case of ironwork set in concrete the iron, having a fairly clean surface when so set, makes a fairly good contact by means of the concrete with the surrounding soil. Small iron pipes running through the inside of lamp-posts to the mains and larger pipes running down to and for a few feet through the ground (even to within a few inches of the rails) form poor earth connections between the rails of a trolley system and other earthed conductors.

V.

Voltage Contour Lines

GENERAL.

A somewhat interesting phase, although only a scientific one, of grounded track return investigations is the plotting of voltage contour lines. While these lines can not be plotted absolutely correctly without data obtained by means so expensive as to be pactically prohibitive, fairly accurate information can be secured by the use of apparatus which can be mounted and carried on a light emergency wagon.

A somewhat detailed description of the apparatus and methods to be adopted in order to carry out this work can be given under three headings: apparatus, survey, and map-work; all the details of which should be under the personal supervision of one man, an expert. The major portion of the necessary apparatus can be designed in the draughting room and built in the car shops of the average street railway company. The surveys can be made by students of some technical college during their summer vacation at a small remuneration. For the information which they obtain of practical scientific electrical conditions, traction plant and street railway operation is very valuable to them; inasmuch as it gives them a renewed inclination for their remaining college work and a preliminary training for some of the duties which will have to be subsequently undertaken by them

APPARATUS.

The first thing that should be located, so as to prevent any loss of time when the remainder of the apparatus is ready, is some light wagon mounted, if possible, on springs, and a one-inch board, twelve inches wide be fastened edgewise against the inside of one of its sides. This board should be planed and long enough to reach from the front to the middle of the wagon, and is intended to serve as a table for the required instrument and some of the wiring, and also as a rough desk for the student having field charge of the survey. The top of this improvised table should be about one inch below the top of the wagon side. The horse should be of a fairly heavy build, and not of a nervous temperament. The required instrument is a below-and-above-zero reading duplex potential-meter (Richmond pattern, made by the Weston Electrical Instrument Company). As drops have to be taken between points situated as much as 1,200 feet apart, it is necessary to have some means whereby about 1,300 feet of flexible twin-conductor electric light cord can be rapidly run out and hauled in for this distance. To meet this requirement, the writer designed a self-winding reel, which, in the main, consists of three compartments formed by means of four triangular cast-iron plates. Fig. 21 is a diagrammatic representation of this machine.

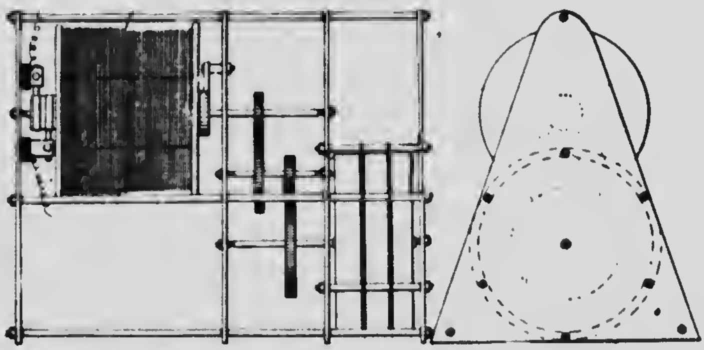


Fig. 21.—Diagrammatic Representation of Apparatus for Use in Securing Data for Plotting Voltage Contour Lines.

The compartment formed by the first and second plates contains a light wooden drum, the diameter of the core being one-half that of the flanges, a projection on the outside one of which flanges is encircled by two insulated brass rings making contact with two end-on brushes held by brush-holders attached to but insulated from the inside face of the first plate. The axle, on which this drum is mounted, is located near the apex of the machine, revolves between the first and the third plates on headless, pointed set-screws, which set-screws are provided with lock-nuts to keep them firmly fixed after they are adjusted, and on it, between the second and third plates, is keyed the lighter of the two pinions of the double reduction gearing.

Near the bottom of the machine, between the second and fourth plates and running clear of the third plate, is located another axle on similar set-screws. On this axle, between the second and fourth plates, are anchored the inner looped ends of three spiral springs, each made of oneeighth inch spring steel two inches wide and forty feet long. The outer looped-ends of these springs are slipped over the bushing of one of the double-ended tie-bolts which hold the plates in position. On the same axle, between the second and third plates, is keyed the heavier of the two gears of the double-reduction gearing.

About midway between the spring and the drum axles is located the intermediate axle on similar pointed set-screws, between the second and third plates. On this axle is keyed the heavier of the two pinions of the gearing, so placed that its teeth are geared into the teeth of the spring axle gear; and on it is also keyed the lighter of the two gears, so placed that its teeth are geared into the teeth of the drum-axle pinion.

The second and third compartments are covered over with one piece of sheet iron, bent to fit and fastened to the plates by means of 14/20 (or ¼ standard) round-head machine screws. In the centre of the cover, for nearly its full width, is cut out about a six-inch portion, over which is fitted a sliding cover, so that the bearings of the axles on the pointed set-screws can be reached from time to time for oiling purposes.

The plates are fastened together by means of double-ended tie-bolts with two nuts at each end (one nut inside and the other one outside of each plate). The spacing between the plates is obtained by means of bushings made out of iron pipe and slipped over the tie-bolts. On the outside of each plate is attached a strong handle, the two points of each plate to which such are attached being strengthened by means of bosses cast on them.

A few points to assist in the construction of one of the machines are as follows: The pattern for the plates should be made in the form of a skeleton frame, to allow for the necessary requirements of the various tie-bolts and set-screws, which frame should then be glued and screwed to a thin board. When the pieces are firmly set, the portions of the board protruding beyond the frame should be sawed off and the pattern, after receiving the necessary draught, be finished in the usual way with black shellac. As only two of the plates require bosses, the pattern portions for these can be made detachable. For drilling, one of the plates should be laid off and centered, the four plates be clamped together and the holes required similarly in the four be drilled simultaneously, care being taken that the size of the hole drilled at any particular point is not larger than the smallest one required by any one of the four (any hole in any one of the plates which is smaller than necessary can be bored out afterward to the size required). Those holes which are not required at similar points in all the plates can be drilled afterward by clamping only two or three of the plates together. The opposite holes in any two plates to be threaded for two set-screws should have the taps run through them simultaneously while the plates are bolted together, so that the screws which act as bearings may have their centres true. The three springs should be separated by two discs of thin sheet iron, the centre holes of which discs should clear the spring axle, and the holes around the circumference clear the tie-bolts but not the bushings. The drum should first be turned in the rough on its axle, the circular rings be then driven on and the whole be finally finished in the lathe, including the oiling and shellacing. When the machine is ready for the electric light cord, which should have a thin inner insulation of rubber, a strap can be used between one of the lathe pulleys and the drum to wind the springs up. When so wound up, one end of the cord can be pushed through a hole in the flange and the two conductors be connected to the two circular rings. The drum can then be allowed to unwind and thereby wind up the cord. Attached to the side of the drum, opposite to the side having the rings, is a ratchet wheel to be used in conjunction with a pawl pivoted on the second plate. This is to check the reel from rewinding when unwound.

To assist the surveyor to stretch his wire and keep it high enough for vehicles to pass under, and also to keep it above the trolley wires of cross-lines, it is necessary to have some light portable poles. Some idea of the way these poles are constructed and used will be gained from an examination of Fig. 22, which is a reproduction of a photograph of the wagon when in service.

These poles, in the main, consist of a tripod supporting the pole proper which is in the centre and made of two poles about one and one-half inches in diameter jointed together by means of a piece of iron pipe about fourteen inches long and firmly fixed in a circular block of wood. The bottom pole, which is about twelve feet long, is permanently fastened in the pipe, while the top one, which is about fourteen feet long, has its bottom end so turned that it can be easily taken in and out of the pipe (ferrule). Near the top end of the pole is screwed a strong iron screw-hook for the wire to slip in and out of. The top ends of the three fourteen-foot poles forming the tripod are hinged to the circular block by means of strong iron screw-eyes.

The bottom ends of the pole and the three legs of the tripod are provided with spikes. These are made by screwing in strong iron wood-screws for about half their length and then grinding the projecting portions to a point on an emery wheel.

Fig. 22.—The Use of Tripod and Pole for Spanning Street Crossings.

SURVEYS.

To use the testing wagon, which is provided with a canvas covering stretched on a light framework, the reel is placed on the rear end and the two wires which run from the brushes are connected in multiple to one of the meter posts. To the other post of the meter is attached a short length of flexible cord with a small iron clamp connected to its outer end. A similar clamp is connected to the two ends of the two wires from the reel. This latter clamp is then attached to a hydrant and the driver ordered to go ahead. As the wire unwinds, it is hooked up on such convenient places as lamp-posts, pole-steps and branches of trees. At cross streets, the portable poles are used. When the next hydrant is reached, the other clamp is attached to it and a reading taken. This clamp is then loosened and the wagon proceeds to the next hydrant, where the clamp is again used and another reading taken. This is repeated until all the wire is unwound and the last reading for this stretch is taken. The wire is then loosened from the first hydrant and allowed to rewind. If the weight of the wire or its resis is sufficient to check the winding, such is easily assis d by one of the attendants.

After readings have been taken on all the streets running in one direction, similar ones are taken on those running at right angles to the first ones.

MAP-WORK.

When all the readings have been taken, the expert works out from them the relative voltages of the different points as compared with a chosen zero—very trying and can be undertaken only by the expert. This consists of reducing the mass of data turned in by the surveyors to figures entered on a rough map, which rough map is taken in hand by the draughting department, and a finished map made on tracing cloth with the required contour lines plotted on it.

Fig. 23 is a reproduction of a map with contour lines which was so gotten up by the writer for the City of Richmond, Va., and it shows, from an electrolytic point of view, a condition very favorable to the traction interests of that city.

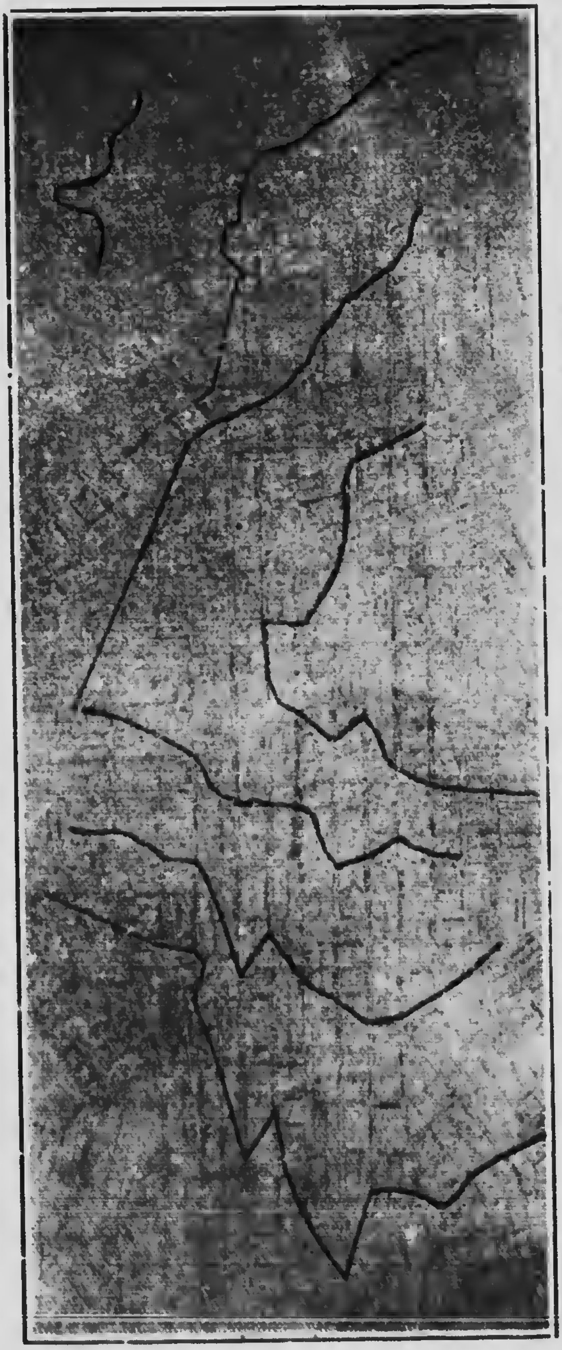


Fig. 23.—Reproduction of Map With Voltage Contour Lines Plotted.

VI.

Rail-Joint Bonding

TRACKS AND BONDING.

Notwithstanding all written and said, and although the average traction engineer is well aware that it is important that the track conditions, from a conductivity point of view, should be kept up to the standard required by modern and approved engineering, it is remarkable how many railroads permit their bonding to deteriorate. This is very regrettable, and can only be explained on the basis that, being hidden from officials, the condition of the bonding is not constantly brought to their notice like the conditions of the other phases of street railroading are. Bond testing should be methodically carried out constantly; this is, as soon as the whole system has been tested, it should be all gone over again and again to the N times. For this purpose a Conant rail-joint testing instrument with the built-up frame contacts (not the poles) should be used.

BANK AND BUNK RAILWAY COMPANY

Bank, Bu.

BOND TEST SHEETS

...... Test. Sheet No. ......

Tests made by..

Date..

Weather..

Preceding weather................ ..for.............. ....days

Locality	Joint No.	North Track		South Track		West Track		East Track	
		N. Rail	S. Rail	N. Rail	S. Rail	W. Rail	E. Rail	W. Rail	E. Rail

Fig. 24.—Report Sheet.

The operator should be a young man of a plodding—very plodding—character, and his assistant be a boy. Both of them should be on the pay-rolls of the maintenance of way department. The young man should receive two dollars, and the boy fifty cents, a day. Both of them should report at the office at 8.30 a.m., be at work on the streets at 9 a.m., go to lunch at noon, be back at work on the streets again at 1 p.m., start for the office at 4.30 p.m., and, on arrival there, enter up the readings on clean sheets, a fac-simile of which is given in Fig. 24, and leave them, before quitting at 5.30

p.m., on the desk of the head of the department. The head, on the first of each month, should turn in the accumulated sheets, with a brief attached criticism of them, to the general manager for perusal.

To make a simple test of the accuracy of the Conant rail-testing instrument, a duplex millivoltmeter (Richmond pattern) is very handy. Such an instrument has been mentioned in a previous article ("Earth Voltage and potential Measurements")* in connection with the first method of testing for stray transmission, and is used by taking the track drop across the joint with one side of the instrument and the drop across three feet of straight rail with the other side of the instrument.

Investigation has shown that good bonding, carried out with one bond at each joint in outlying sections and two bonds at each joint where the loads accumulate, with, perhaps, three bonds at each joint in some special cases (where the load is exceptionally heavy), will give results showing, in many cases, joints and straight rail as equal; this is, the conductivity of three feet of joint (eighteen inches each side of the junction of two rails) is the same as that of three feet of straight rail (rail without any joint); in other cases the results will show that the joints are equal to six or nine feet of rail. Where the bonding is out of order, the results, of course, will show much worse conditions. Where the tests give joints as being equal to more than six feet of straight rail, the joints ought to be rebonded.

Riveted and Soldered Bonds.

The practice which is often followed of drilling the bonding holes in the rails beforehand, to insert the bond terminals in, cannot be too strongly condemned, unless they are drilled slightly smaller than required and are reamed out to the right size just before the bonds are installed. This because the holes will accumulate a certain amount of moisture and oxide in a very short time, which will, sooner or later, cause imperfect contact between the bond terminals and the rail metal. Bonds should be flexible, and preferably of the ribbon type. The bond terminals should be large—very large—and welded by some heat process to the ribbons (not pressed), and when inserted in the rails should be swaged up by compression applied to the head and the other end. When soldering can be carried out, the terminals and the rails should be sweated first; and when the terminals have been compressed heat should be applied to make the two sweated surfaces run together. The terminals should then be compressed again.

* Chapter II., page 12.

Electric-Weld Bonds.

As generally known, the question of how best to obtain a permanently satisfactory electrical connection of sufficient conductivity across rail joints, has been a very important one. Starting with a multitude of ground connections, this question has been dealt with successively by using galvanized iron wire, copper wire of increasing conductivity, specially prepared bonds (first of the solid and then of the ribbon type), bonds soldered to the rails and finally bonds electrically welded to the rails.

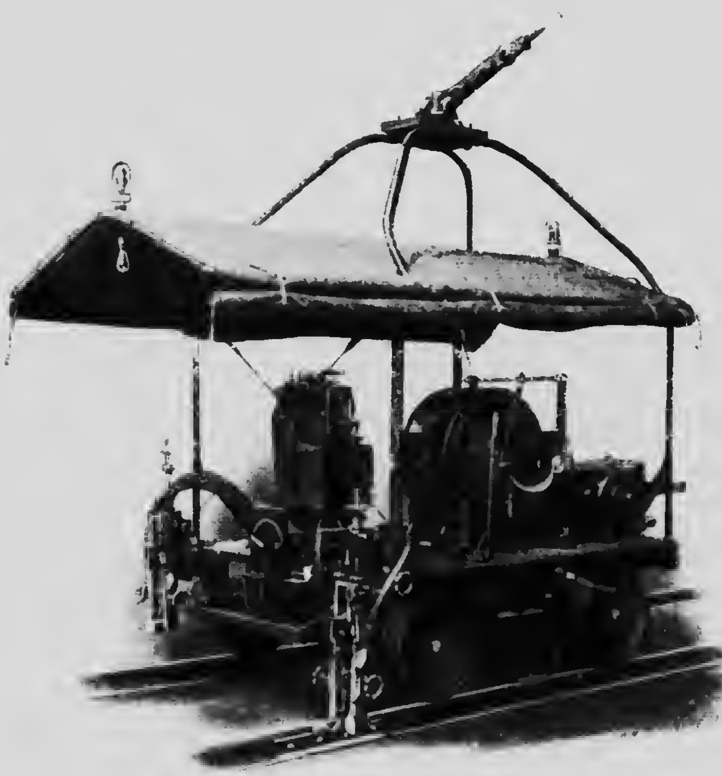


Fig. 25. Apparatus for Electric-Welding of Bonds.

While retained by the Toronto Street Railway, the author had opportunities to observe and consider the method of attaching bonds to the rails by means of apparatus supplied by the Electric Railway Improvement Company, of Cleveland, and illustrated in Fig. 25. The method adapted is to first grind the side of the tread of each rail and then after clamping the bonds to the clean surface, one surface at a time, to apply at a low voltage a high amperage by means of the clamp. The result is, without any question, the most satisfactory method of rail bonding. The amount of copper used is almost reduced by this process to a minimum. The carbons used in the welding clamp, of course, require very frequent replacement, but the actual cost for this item per bond is fractional.

SPECIAL-WORK BONDING.

Those who are practically acquainted with track conditions, considered from the point of view of conductivity, know, more or less, that it is very difficult to keep the bonding of special work, as it is usually carried out, up to standard. This is due to several reasons: the three main ones being the more than usual amount of motion at the joints, which loosens and breaks the bonds; the use of small lengths of rail to "make-up"; and the extra trouble which is experienced in getting at the bonds for repairs, especially when the special work is the result of cross lines with the thereby heavy traffic. Carefully taken short track-drop readings generally show, when the bonding on clear runs is in fairly good condition, that most of the total drop is due to the drops across the pieces of special work (steam railroad crossings being the worst offenders) unless the ordinary special bonding is new, when the drops across special work will be less than that across equal lengths of clear track. This has been somewhat generally understood for several years; and, as a result it has been customary to lace the special work with lengths of bare wire, usually trolley wire, though in some cases galvanized wire has been used. The writer, therefore, adopted for such points a class of bonding which he terms special long bonding, the details of which will be given further on.

When new track is being laid, the special work and the ends of the clear runs should be connected together without the use of short lengths of rail to make-up; this is, if fifty-foot rails are being used and the distance to be connected up is sixty feet, one fifty-foot length and a 10-foot length should not be used. What should be done in such a case is to cut two thirty-foot lengths off two fifty-foot rails and use them to make-up the sixty-foot space. Short lengths, therefore, when used, should always be used on the clear runs. The special work should be extra ballasted, and the extra ballasting should be continued on under the clear runs (gradually tapering) for a short distance. It is also a good plan to use, for the top of such ballasting, a dressing of concrete. This concrete should be rammed in after the special work and clear runs have been bolted up; and, if possible, no cars should be run over it until the concrete has set. If this work is being done on a road which is only operated during the day, the concrete should be rammed in as soon as the last car has passed, which will give it a few hours to set. This policy will reduce the joint-motion at these points to a minimum; and it is absolutely necessary that the special work should be carried out in a very substantial manner when it is the result of a steam railroad crossing

In track maintenance it is often found that the joints at certain points of the clear runs show considerable motion At the points where repairs are found to be constantly required (evidence of which will be shown by the repeated bond tests), it will generally be found, on examination, that the trouble is due to the unstable character of the foundation soil as a result of surface or other drainage. The cure for this is to dig out the under-soil for about two and one-half ties each way, place a longitudinal tie under and attach it to the four tie ends and then fill in with stone ballast, which should be well rammed. If the motion is due to rotting sleepers (ties) as a result of soggy ground, the ties should be replaced with creosoted ones, creosoted by the vacuum process (not the superficial one); and if the conditions producing rot are extreme (alternating sogginess and dryness) the ends of the ties should, before installation, be dipped into a tank of P. & B. paint, thinned down with carbon bisulphide, a commercial quality of which can be bought by the carboy. The use of iron ties is not recommended.

The author is not favorable to the use of iron ties, because the surface of track metal-work grounded is considerably increased thereby; nor is he favorable to the practice of laying rails in concrete, because the efficiency of electrical contact between the rails and the earth is, as a result, much greater—vide chapter IV., page 32.

The special long bonding, which will be described in detail, consists of the laying of sufficient extra copper to act, so far as the conductivity of the return is concerned, as a factor of safety in the case of deterioration of the special work bonds. The cables used for these long bonds may be laid in concrete, and there ought to be one cable for each rail. It is much preferable, however, to use, instead of the concrete, box troughs with a minimum cross-sectional area, into which, after the top has been nearly all nailed down, melted pitch, mixed with a little tar to keep it moderately soft, is poured.

The use of two special long bonds instead of four with double-track roads is not the best practice; nor can the use of bare instead of insulated cables laid in a considerable superficial area of concrete be accepted as good practice— vide chapter IV., page 32.

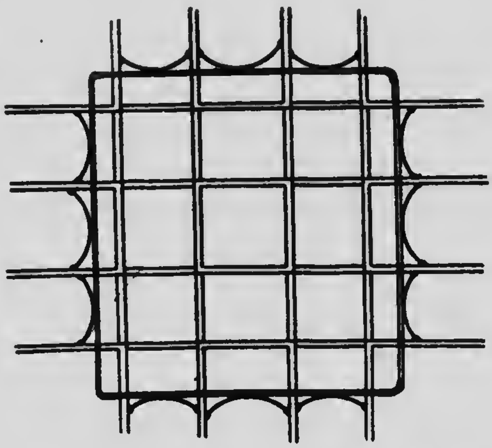


Fig. 26 (a).—Old Method of Rail Lacing.

Fig. 26 (a) illustrates the old-fashioned method of rail-lacing, while Fig. 26 (b) represents how similar special work is provided with special long bonding.

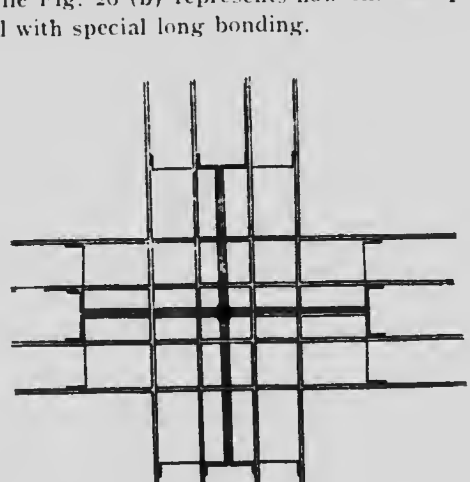


Fig. 26 (b).—Special Long Bonding of Special Work.

When a turnout is somewhat complicated on account of it forming the junction between two lines, the special long bonding becomes more complicated. Fig. 27 shows the old lacing method; while Fig. 28 illustrates the modern and

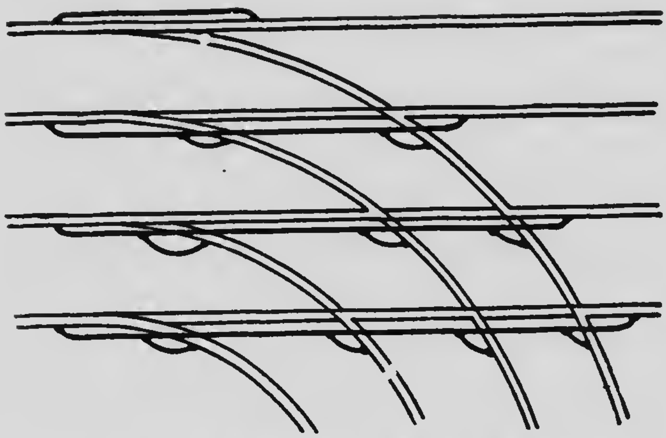


Fig. 27.—Original Method of Bonding at Junction.

approved plan; in which case, as will be noticed, part of the special bonding is laid to one side of the tracks. This is because it is often very difficult, when installing this work

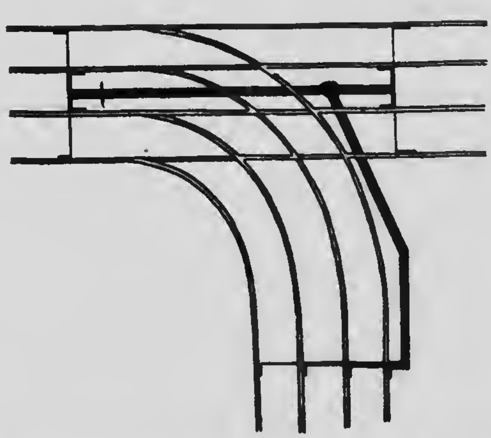


Fig. 28.—Improved Method of Bonding at Junction.

in connection with track which has been previously laid, to dig a trough near the tracks on account of the many ties.

Fig. 29 clearly illustrates how simple turnouts were

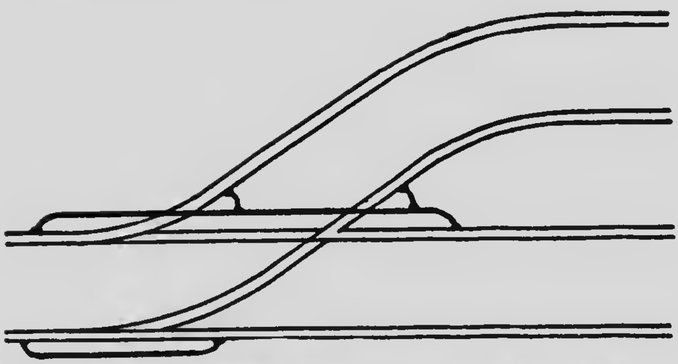


Fig. 29.—Original Method of Turnout Bonding.

originally strengthened. Such a plan has, however, been proved to be exceptionally weak; and the method which should be adopted is illustrated in Fig. 30.

Fig. 30.—Improved Method of Turnout Bonding.

Although there are many other forms of special work, it is not necessary to illustrate all the combinations which can be worked out; but it is believed that the few examples given will assist the track engineer to understand the principle involved.

A few of the details to be observed in connection with this work are as follows:—

The cable ought to be double-braided weatherproof, with a stranded core made up of tinned wires if there is any considerable amount of soldering to be done. The size of the cables ought, according to the loads at the different points, to run from 200,000 to 1,000,000 circular mils.

The terminals which are used to connect the cables to the rails are illustrated in Fig. 31, the ribbons of which should be spread out and coiled around the ends of the cables (previously cleaned with gasoline) and then soldered by pouring melted solder over the junctions of the two. This, provided that the method of electrical welding of bonds is not adopted.

The number of rail connections at each point should vary from three to six, according to the loads to be taken care of.

All the cables at each piece of work should be bared about the middle, then cleansed, bound together and finally be sweated and covered with tape and painted with P. & B. paint.

Fig. 31.—Cable Terminal.

A slight kink should be made in each cable end near to the rail contacts; and, when the contacts are made, they should receive a liberal covering of the insulating paint.

To carry out this work, the first requirement is that accurate tracings to scale should be made of each piece of special work. Blue-prints from these should be then sent to the electrical engineer, who should mark on them the sizes of the cables to be used and the price of such per foot. They should then be handed over to the track engineer. This is the man who by a little originality and patience can save a few hundred dollars. A couple of hours spent on the blue-print of each piece of work will be found to be a paying investment. When the track engineer has marked on each blue-print the points to which the cable ends are to be connected and the route which the cables must follow, it should be returned to the drawing office with any notes which may be found necessary. The drawing office should then complete each tracing, and as each one is finished send a blue-print from it to the electrical engineer, so that he may check the sizes of the cable given. When so checked, he should forward the blue-print to the track engineer, by whom it should be handed to the foreman on the job. Any deviations from the blue-prints which the foreman may find necessary should be mentioned in his daily reports to the track engineer, by whom the drawing office should be notified, so that they may make the necessary changes on tracings.

It is often necessary that this work be simultaneously installed at several points; in which case the track engineer will probably find it necessary to have an assistant to deal with instead of his regular foreman. This assistant should be a bright, active and intelligent young engineer, with two quick eyes in his head and a fine quality of gray matter behind them; in fact, an embryo expert. His remuneration should be at least $90 a month. Particularly must he keep his eyes on every part of the work undertaken by the bonding men. The number of men in each gang on the special long bonding will vary, according to the area covered by the special work, from six to twelve; and they should be strong and active street laborers at the highest local rate of pay. Each gang should have a boss. College technical students who are husky football players make good bosses; remuneration, $50 a month; hours, 7 a.m. to 6 p.m. Some leniency should be allowed toward the men on hot days, especially during the middle hours; and plenty of iced water, with a liberal allowance of oatmeal in it, should be provided.

As for auxiliary insulated copper (return feeders), they in the majority of cases will be found to be only necessary where the tracks converge near the power-house, provided that the ordinary and special long bonding has been carried out as has been already outlined. The cables, for this purpose, should be insulated from the low voltage side of the generators right up to the connecting points, each of which points should be the junction of the middle points of the cables used for the special long bonding of a piece of special work. Such connections, after they have been well soldered, should be plentifully taped and thoroughly painted with insulating paint.

VII.

Lowering "Track Drops"

EARTH AND TRACK VOLTAGES.

To logically consider this and several other questions, the author has found, as a result of some very thorough analytical research and practical investigations, that it is absolutely imperative to consider electrical physics in an unorthodox way by treating each electrical phenomenon as the "effect" from a "cause," the "cause" being the abnormal position of the molecules of matter. Now this abnormal state of affairs constitutes a difference between two points, or what may be termed an attraction between two points; for two bodies in an equal state cannot have any effect the one upon the other. At Christmas, 1890, the author delivered an address before a branch of the Agassiz Association in Cote St. Antoine, (now Westmount, Montreal), at which he fully explained why the hackneyed statement that "Two like electricities repel each other" is a misstatement. To strengthen the position taken by the author at the time, he may say that he had been for several years engaged in metallurgical, mining, mechanical and electrical engineering, and was, besides, the only man in Canada engaged at that time as an ironworks chemist. He had, also, been for five years a resident in Canada.

For convenience, abnormal position of molecules (electrically) may be termed "Electrical Condition." Voltage, therefore, is the intensity of "Electrical Condition" at one point only; and potential is the difference between two points of this condition. Direction of electrical transmission (electrical action due to a difference of "Electrical Condition" between two points), being self-explanatory, needs no description.

To somewhat reiterate in regard to that which has been given before, it is advisable, perhaps, in order that the reader may easily follow and assimilate the diagrams and arguments which will be used, to recall to his memory some elementary information, probably received in his schoolboy days, by defining in a clear and simple manner the meaning of the term zero. For, in the systematic consideration of any condition (abnormal position of the molecules) of matter, it is requisite to have a starting point which is so termed in order to argue clearly and to measure correctly and comparatively. For all consideration is but comparison; and this though it has been said that "comparisons are odious," which is an unfortunate platitude, as "active searching after the truth" and "comparisons" are synonomous.

That absolute-zero is synonomous with "nothing" is generally understood by students of philosophy. When one deals with something, therefore, such "something" is a plus quantity to "nothing" or absolute-zero. As it is, however, often impossible, when dealing with some particular branch of the science of "change of position" (motion or physics), to obtain absolute-zero, it becomes necessary to adopt an obtainable plus condition as an arbitrary zero; and, if possible, such should always be to absolute-zero the same amount plus.

That an arbitrary-zero is as necessary, in many instances, in the case of electrical measurements (measurements being only one form of consideration) as in temperature measurement is no hypothesis but an actual theory, a theory being the words used in speech or writing to designate a fact. A theory, therefore, is a deduction from practice. Unfortunately, however, the present state of that branch of the science of the abnormal position of molecules or one phase of the science of electrical physics is such that a standard arbitrary-zero can not be adopted. For the voltages of different points of the earth vary, though they are, over a somewhat circumscribed area, approximately equal during inoperation of earthed electrical transmission mediums. And so the normal voltage of the earth over a circumscribed area constitutes for such locality the most satisfactory arbitrary-zero which can at present be obtained.

Very interesting in connection with this phase of the subject being dealt with was the appearance, in the Electrical Review of New York (August 30th, 1902) of an abstract of a lecture delivered shortly before to the members of the Gas Institute of Great Britain, a portion of which abstract reads as follows:—

"Taking the earth itself generally as being at zero pressure, or to use the water analogy, at zero level or head, we may consider that one end of the rails would, in the extreme case mentioned, be fifteen volts above the zero, and the other fifteen volts below."

A very important factor, apparently lost sight of when the lecturer expressed the foregoing opinion is (though the electrical condition of the earth over a given area, such as that over which an average traction system is operated, is more or less equal at all points during inoperation) that the electrical condition or voltage of that portion of the earth contiguous to the earthed return of a traction system in operation varies from point to point, the voltage of each point being more or less controlled by the nearest portion of the earthed return. Now to agree with the lecturer's examples and to have a portion of the earth, of any practical dimensions in so far as the question at issue is concerned, at a lower voltage than normal (arbitrary-zero of the district) would require two conditions to exist at the same time:

1. That the low-voltage side of two generators arranged as a three-wire system must have a much lower voltage than the arbitrary-zero of the district by locating the power-house close to the middle point of a fair length of track and by connecting the neutral point between the two generators to this middle point of the track.

2. That the "negative" side of the foregoing three-wire system must feed the trolley-wire running in one direction from the power-house and that the "positive" side of this three-wire system must feed the trolley-wire running in the other direction from the power-house.

Now both these conditions are obtainable, but not with plant arranged as assumed by the lecturer. For plant arranged as assumed by him would, practically speaking, have arbitrary-zero voltage at the low voltage side of the generators, and a higher voltage at a point at a distance away. The experiment with a 900-foot surface plate in the bed of a river (described before) proved that the low-voltage side of the generators was about 12 volts below the voltage of the earth and river at the point where the plate was immersed due to insulated auxiliary returns. The voltage of the immersed plate, however, was about 10 volts lower than that of the water a few (about five) feet away. Again, the author has found a difference of voltage between the two rails of a track in the Bronx (New York City) of about 60 volts, or 60 volts difference between two earthed conductors situated only 4 feet 8½ inches apart. Apropos of which, it may be said that high potentials between earthed conductors are indicative of high resistance and, contrary to the usually accepted ideas, of none or very little stray transmission; while very low potentials between earthed conductors are indicative of comparatively low resistances and, again contrary to accepted ideas, of the transmission at times of considerable stray energy.

Returning to the lecturer's finding again, Fig. 32 diagrammatically represents earth voltage conditions as assumed by him. Now, obtaining such conditions by means of two generators run as a three-wire system with the neutral earthed to the track and the other two wires connected the one to one trolley running in one direction and the other to another trolley running in the opposite direction, then the half

Fig. 32.

of the figure with the cross-section line shading would represent the earth's voltages in the one direction, and the other half of the figure with the straight line shading would represent the earth voltages in the other direction. No shading would represent arbitrary-zero voltage, while the depth of the shading would represent, according to whether it were on the one or the other side of the figure, the degree of voltage above or below arbitrary-zero voltage. The actual earth voltages which would exist (in the case of plant arranged as assumed by the lecturer) would have to be diagrammatically represented as shown in Fig. 33.

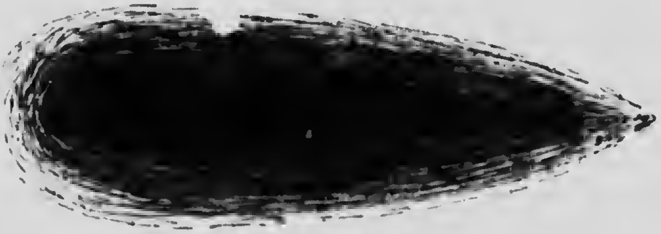


Fig. 33.

The lecturer's diagrammatic illustration marked Fig. 3 is the foundation for the remaining illustrations used by him. Now it is reasonable to assume that the accuracy of his following illustrations together with his explanations of and deductions from them will, in the main, depend upon the accuracy of the fundamental principles and reasoning accepted by him and involved in his Fig. 3.

Fig. 34 is a reproduction of his Fig. 3; in respect to which he explained that E E is the rail-return and that its

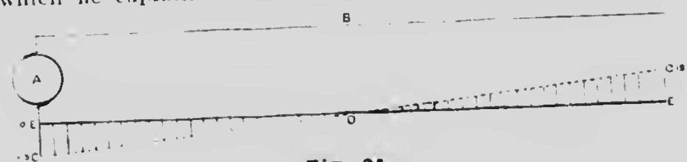


Fig. 34.

potential (? voltage) in regard to the adjacent portion of the earth is represented by the dotted line C C. He further explained that the rails are 15 volts "positive" at the far end and 15 volts "negative" at the near end.

Now in "ye olde days" of electrical traction the majority of systems had a short mileage (or a mileage of short runs), a fairly light load and a ridiculously small cross-section of copper connecting the rails to the low-voltage side of the generators. As a result, the difference of voltage between the outer end of the track and the low voltage side of the generator—provided that the bonding was new—amounted to about 30 volts; while the difference between some point of the track near to the power house and the low-voltage side of the generator would be about 15 volts. The lecturer's conclusion, therefore, was, though wrong, a somewhat natural one and in agreement with that of many others who have dealt with similar conditions.

Figures 35 and 36 will help the reader to more easily understand the answers given. Fig. 35 represents the home

Fig. 35.

end of the rails running right up to the power-house and connected to the low-voltage side of the generators, in which case the low-voltage side of the generators will only be one or two volts lower than the arbitrary-zero of the district. Fig.

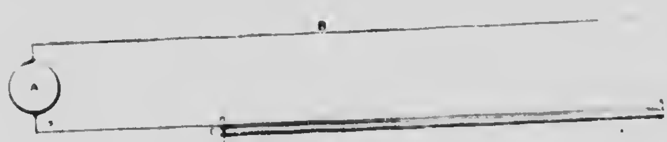


Fig. 36.

36, on the contrary, represents the home end of the rails as ending at a distance away from the power-house, and as being connected to the low-voltage side of the generators by a greater or lesser length of insulated copper, the drop along which may be assumed as 13 or 14 volts. In this case, therefore, the voltage of the low-voltage side of the generators will be about 15 volts lower than the arbitrary-zero of the district, this is, the self-zero of the system will be −15, and the arbitrary-zero be 0.

If the lecturer's finding as to the voltages existing in connection with his assumed arrangement of plant were correct, it would be necessary to plot them as illustrated in Fig. 37; in which, Z Z being the arbitrary-zero line and A

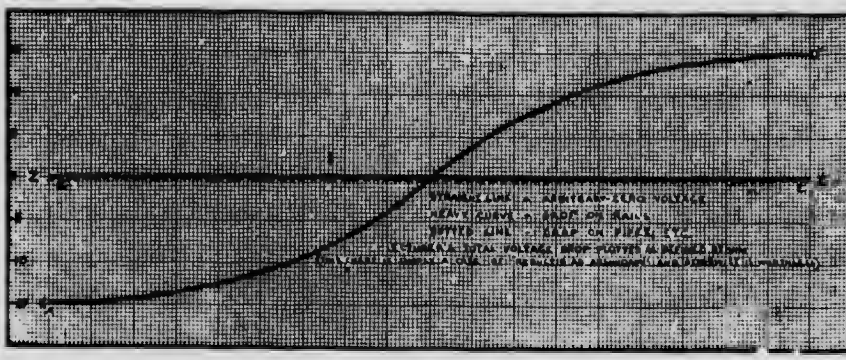


Fig. 37.

the voltage of the low-voltage side of the generators, C C′ would represent the voltage at different points of the rails and the dotted line E E′ would represent the voltage at different points of the contiguous portion of the earth and the pipes. His finding being incorrect, however, his total drop of 30 volts would have to be plotted as in Fig. 38; in which,

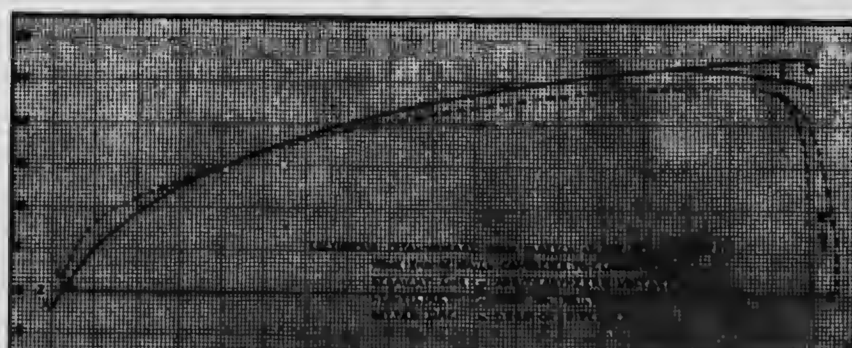


Fig. 38.

Z Z being the arbitrary-zero line and A the voltage of the low-voltage side of the generators, C C′ would represent the voltage at different points of the rails, while the voltages of different points of the contiguous earth and pipes would have to be represented by the dotted line E E'.

As is generally known, the English Board of Trade has among its rules and regulations applying to the use of grounded returns by "tramways" (street railway) companies, one which reads as follows:—

"7. When the return is partly or entirely uninsulated, a continuous record shall be kept by the company of the difference of potential" (? difference of voltage) "during the working of the tramway between the points of the uninsulated return furthest from and nearest to the generating station. If at any time such difference of potential" (? difference of voltage) "exceeds the limit of seven volts, the company shall take immediate steps to reduce it below that limit."

Now, while this regulation is not elastic enoughto suit, in all fairness, every road using earthed returns, it is a good provision and can be lived up to in many cases without any financial hardships—provided that modern approved engineering practice is rightly applied in respect to local conditions. Unfortunately, however, the engineering principles affecting the question of grounded transmission mediums have not, or not until lately, received from engineers and especially from general managers and operating engineers the attention due them; in fact, the principles followed up to lately have mostly been of the "penny-wise and pound-foolish" order. For this, the financial "end" (and general managers, generally) have not been to blame. For they rely on the engineering "end," especially the operating staff; which "end," unfortunately, while developing other engineering portions of traction systems to a state of efficiency deserving of the utmost credit, has, apparently, considered that anything was good enough for the return, neglecting in many cases to keep up to standard even the condition of the return from a good conductor point of view. As for auxiliary copper, such has been considered as something only to spend money on if outside parties have been able to force the necessary expenditure for it. And so many companies, appearing to believe that auxiliary copper is a dead loss as an investment—which is not the case—have endeavored and do endeavor to live up to the regulation of the Board of Trade (just quoted) in the "letter," but not in the "spirit," of the law by using negative boosters. The "spirit" of the law could be lived up to by dividing a length of track into sections and the use of insulated return copper from each section—provided that negative boosters were inserted in series with the insulated returns from the more distant sections of the track.

NEGATIVE BOOSTERS.

A negative booster is simply a low-voltage generator inserted in series in the return. Now assuming a system having the home end of the track connected to the low-voltage side of the generators and having a track drop of 28 volts, Fig. 39 will then illustrate diagrammatically the voltages of

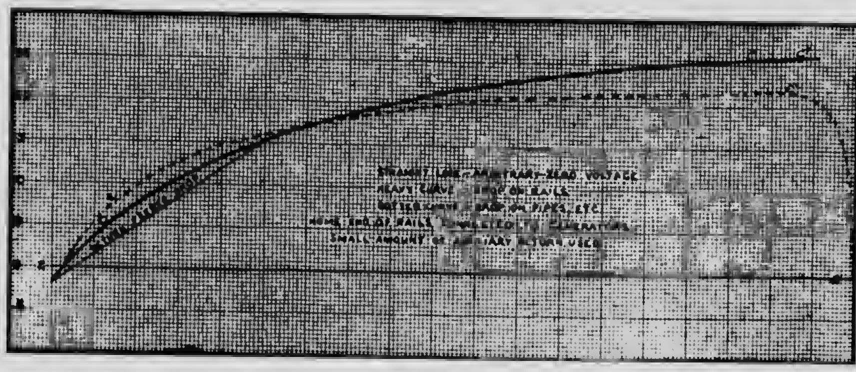


Fig. 39.

this system; in which, Z Z being the zero line and C C′ the voltage of the track, E E′ will represent the voltages of the pipes and the portion of the earth contiguous to the track.

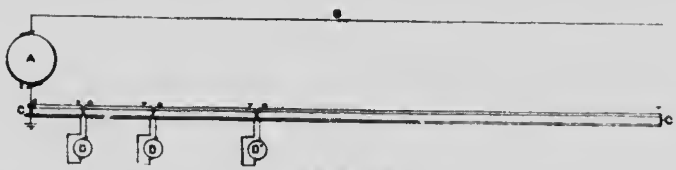


Fig. 40.

If negative boosters are inserted in series with the track return, as diagrammatically shown in Fig. 40, in which A is the generator, C C′ the return, and D, D′ and D″ are negative

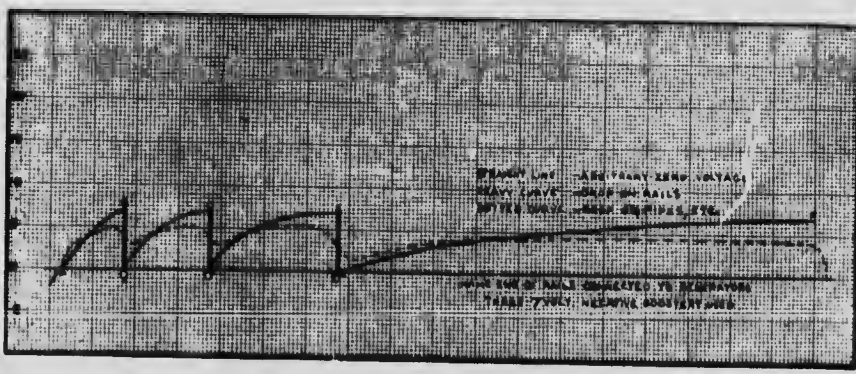


Fig. 41.

boosters located, owing to the load, at points 1½x, 3½x, and 6½x feet distant from the power-house; then, if each booster has a boosting electromotive force of 7 volts, the voltage conditions of the system will have to be diagrammatically represented as in Fig. 41; in which, Z Z being the arbitrary-zero line and A B D C D′ E D″ F the voltage of the track, the dotted line will represent the voltages of the pipes and portion of the earth contiguous to the track.

Having considered the result with boosters inserted in series with the track return, let us now assume a case as diagrammatically represented in Fig. 42; in which A is the

Fig. 42.

generator, C C′ is the track return connected to B the low-voltage side of the generator, D O P is a second insulated cable connecting the track to a booster R, and that R is connected to B. Assuming the track drop between D and B to be 7 volts and the booster to give a boosting electromotive force of 7 volts, then B will be o (arbitrary-zero voltage), D will be 7 volts higher and P be 7 volts lower. The drop along D O P will be, therefore, from 7 to —7 or 14 volts. As can be understood, this arrangement will, practically speaking, not improve matters from an electrolytic corrosive point of view. For the sole result of the use of the negative booster will be to lessen the amount of copper required between D and B.

To obtain the same voltage conditions (as in the last example) without a booster would require that the amount of copper between D and P be doubled. Assuming, therefore, such conditions of voltage, $C = \frac{I}{R}$ calculations, which any engineer ought to be able to work out for himself, will show, approximately, that interest charges on capital expenditure together with the cost for booster operation (when boosters are inserted in series with feeders) about balance the interest charges on capital expenditure for feeders without boosters—when the sucking points are situated about 4,000 feet away from the power house; this is, at points situated not further from the power-house than about 4,000 feet, all copper is a better investment than are boosters and less copper.

As power-houses are generally located near to the point where radiating tracks come to a common centre, and as the majority of the track drop takes place in this restricted area of convergence (due to the fact that the track drop is small in outlying sections of this restricted area if the track bonding, by frequent bond testing and repairs, is properly maintained), the conditions met with do not require sucking points (equi-voltage points) to be located as far away as 4,000 feet from the power-house, and so no boosters are required. If, however, the system to be dealt with is one consisting of a long straight run of track, the main length of the outlying sections may be treated as one system by the use of two or more return copper lines with a negative booster inserted in each, while the home section may be treated as another system by the establishment of equi-voltage points on it and the use of return copper only.

EQUI-VOLTAGE POINTS.

Equi-voltage points are obtained by running insulated cables from the low-voltage side of the generators to suitable points of the track. The cables so run must be of such sizes as to produce equal drops between each of the points and the generators. Thus if two track points A and B are chosen, A being one-quarter of a mile and B one-half of a mile from the generators, then, if the amperage loads at A and B be equal and a 1,000,000 c.m. cable be laid to A, two similar cables will have to be laid to B; and, as B is twice as far as A, the amount of copper between B and the generators will be four times the amount between A and the generators. With this method, if the drops from A and B to the generators are each 15 volts, and the home end of the rails are not connected to the generators, then A and B will each be at arbitrary-zero voltage and the low-voltage side of the generators (self-zero of the system) will be —15 volts.

Apropos of the establishment of equi-voltage points, it may be said that the results, so far as track drops are concerned, are the same as if each point were the location of a substation, as is the case with roads like the Manhattan Elevated and Subway of New York; and it was after the author's investigations and drafting of certain drop curves in connection with the former road, together with some preliminary investigations in Richmond (Va.), that Lewis B. Stillwell, Frank N. Waterman and the author decided that this method constituted the true solution of the question at issue.

Figures 43 and 44, each drawn to the same scale as Figs. 39 and 41, will enable the reader to appreciate the advantage, from an electrolytic corrosive point of view, of the establishment of equi-voltage points.

Fig. 43 represents the result obtained by the use of several insulated return feeders to different points—the method which has generally been adopted by better-class roads.

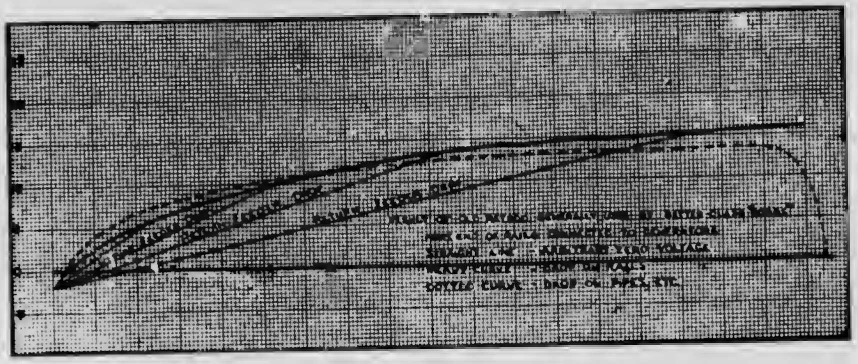


Fig. 43.

Figure 44 diagrammatically represents the results obtained by the adoption of three track points as equi-voltage points; in which, Z Z being the arbitrary-zero line and the

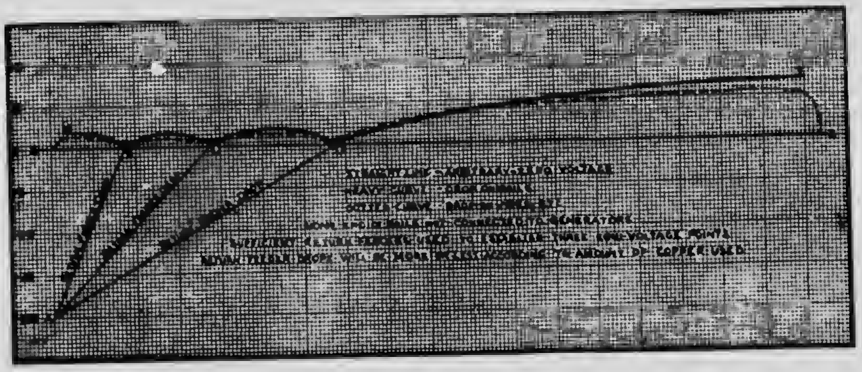


Fig. 44.

home end of the track not being connected to the low-voltage side of the generators (self-zero of the system), A is the voltage (say —20) of the low-voltage side of the generators, B, C and D are the equi-voltage points of the track having arbitrary-zero voltage (o), HB, BC, CD and DT represent the voltage of the track, AB, AC, and AD represent the drop between the track at the equi-voltage points and the low-voltage side of the generators, and the dotted line represents the voltage of the pipes and portions of the earth contiguous to the tracks.

V.

Transverse Stray Transmission.

FACTORS.

Preliminary.

Having treated in a cursory way the general conditions, apparatus, tests and improvements connected with the subject of the electrolytic corrosion of metals earthed in the neighborhood of grounded returns, the writer will now endeavor to take up a very interesting phase of this question. This is the factor which he has termed "Transverse Stray Transmission."

Referring to a previous chapter under the heading of "Stray Transmission," it can be taken for granted that the relative rail, pipe line and earth resistances constitute the really important factor affecting the question at issue; and particular is this the case when one remembers how very much greater is the resistance of a given length of pipe-line than that of a given length of laid rail provided that the bonding of the latter is maintained in a good condition.

In order to deal in an approximately correct way with this relativity of return resistances by the use of plain arithmetic, it is necessary to allow that a certain portion of the earth acts as a connection between the rails and a contiguous pipe-line, and this portion may, for convenience, be termed "Soil," while the remainder of the earth affected may be termed "Earth." Bearing on this subject, Professor Blake, in the "Electrical World and Engineer," (New York), of December 16th, 1899, gave the following data in respect to the resistance of cast-iron pipe and pipe joints:—

Pipes—Water.

Class of pipe:—Six-inch cast-iron.

Length of pipe sections:—Twelve feet.

Average resistance of each length of pipe:—0.000,345 ohm.

Time pipe had been in use:—Thirteen years.

Average resistance of each joint:—0.0092 ohm.

Total resistance joints (58):—0.535 ohm.

Total resistance of pipe-line (687 feet):—1.091 ohms.

1,000 feet of such pipe-line would have, therefore, a resistance of 1.588 ohms.

Rails.

For rail resistances, the following data may be assumed:

Class of rail:—Girder.

Resistance of 1,000 feet of rail:—0.006 ohm.

Length of each joint:—Three feet.

Number of joints to 1,000 feet of laid rail:—Thirty-three.

Equivalent in straight rail of each joint:—Eighteen feet.

Equivalent in straight rail of 1,000 feet of laid rail:—1,500 feet.

Resistance of 1,000 feet of laid rail:—0.009 ohm.

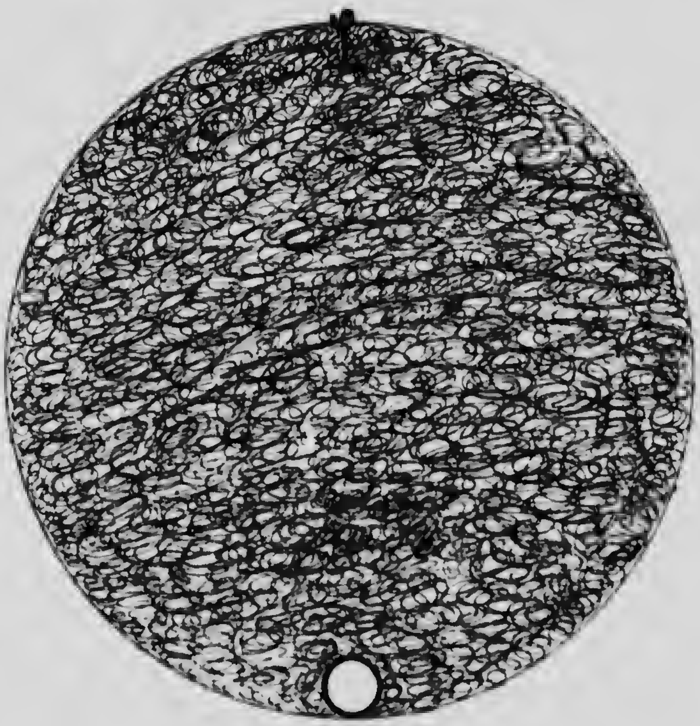


Fig. 45.

"Soil."

A lower "Soil" resistance than is generally allowed is forty ohms for a block three feet deep with connecting faces of three feet by three feet. On this basis, however, assume a rail laid parallel to and ten feet away from a six-inch cast-iron water main; in which case, though the cross-section of the soil directly connecting the rail and pipe in the case of the illustration (Fig. 45) is ten feet, by only a narrow connecting face, it must not be forgotten that the real cross-section of the connecting soil, due to by-paths, is equivalent to soil with a much greater width of connecting face. Consider, therefore, that the cross-section of the connecting "Soil" in the example chosen is equivalent in area to that of a circle having a diameter of ten feet, or, roughly, to a block of soil having a depth of ten feet and a width of eight feet. This is a liberal allowance; and it is probable that tests properly carried out would show that the equivalent area is less, and the resistance, therefore, greater.

Now if soil three feet deep with connecting faces three feet by three feet has a resistance of forty ohms, a block of "Soil" ten feet deep with connecting faces eight feet wide by three feet long will have a resistance of $40 \times \frac{10}{3} \times \frac{3}{8} = 50$ ohms. On this basis, 5,000 feet of "soil" will have a resistance of $50 \times \frac{3}{5000}$ or 0.03 ohm.

" Earth."

" Earth " resistance may be taken as nil for limited areas.

General.

As to the factor of one or more rails, it must be remembered that the stray transmission between one rail and a pipe line with a load 1x will be, approximately, the same as that between two rails and a pipe-line when the load on each rail is ½x, or between four rails and a pipe-line when the load on each rail is ¼x. For all practical purposes, therefore, it can be assumed that there is only one rail, and that it is carrying the full load.

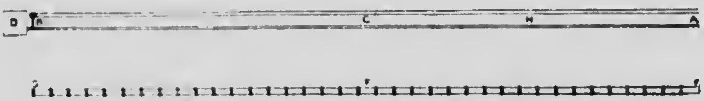
Now consider that Fig. 46 represents, diagrammatically, 10,000 feet of rail laid parallel to and ten feet away from 10,000 feet of pipe-line; in which figure AB is the rail with its middle point at C, D is the power-house and EG the pipe-line with its middle point at F.

Consider a return ampere-load of 250 amperes evenly distributed along AB. This would be equivalent to a return-load of 250 amperes applied at the middle of AB at the point C. As a result, this load would have, roughly speaking, three paths to the power-house D. The first path would be by means of the rail from C to B. The second path (as transmission would be, practically speaking, downward from half of the rail to "Earth," and then upward to the other half of the rail from C to B) would be backward by means of the rail between C and A, the soil between AC and EF to the "Earth," from the "Earth" through the soil between FG and

CB to the rail between C and B, and the rail to the power-house at D. The third path would be similar to the second path with the exception that the pipe-line EG would replace the "Earth."

ARITHMETICAL EXAMPLE.

With the data and explanations which have been given, it is now possible to calculate, approximately, the proportional amperage which will be transmitted by each of the three available paths.



Power House Track and Water Pipe, Fig. 46.

First Path.

The rail between C and B. Length, 5,000 feet. Resistance of 5,000 feet of laid rail = 0.009 × 5, or 0.045 ohm controlling the amperage of this path.

Second Path.

The backward transmission by AC of part of an amperage load applied at C will be controlled by resistance as if this part of the load were applied at H, the central point between A and C; and this resistance will be equal to the resistance between H and C. From H to C is 2,500 feet. 2,500 feet is equivalent in resistance to 0.009 × $2\frac{1}{2}$, or 0.0225 ohm. The resistance of the soil between AC and EF has been calculated as 0.03 ohm. The earth is 0 ohm. The resistance of the soil between FG and BC has been calculated at 0.03 ohm. The controlling resistance of CB in this case will be similar to that of AC, or 0.025 ohm. Summed up, these controlling resistances will be:

$$0.0225 + 0.03 + 0 + 0.03 + 0.0225, \text{ or } 0.1050 \text{ ohm.}$$

Third Path.

The resistance controlling the amperage of the third path will be similar to that controlling the second path plus half the resistance of EF and half the resistance of FG. The resistance of EF will be, at 1,588 ohms per thousand feet, 7.94 ohms; while the resistance of FG will be the same, that is, 7.94 ohms. Summed up, the controlling resistance of the third path will be $0.105 + \frac{7.94}{2} + \frac{7.94}{2}$, or 8.045 ohms.

Terming these three paths, respectively, as rail-return, earth-return and pipe-return, the resistances controlling the division of amperes will be, proportionately:

Rail-return	45
Earth-return	105
Pipe-return	8,045

from which, with a load of 250 amperes, the division may be calculated as:

Rail-return	174.32 amperes.
Earth-return	74.71 amperes.
Pipe-return	0.97 amperes.

It can thus be understood that longitudinal transmission by means of pipe-lines is so small that the hue and cry which has been raised about it has been very much a case of making "A mountain out of a mole-hill." Assuming six car lines with parallel water-pipes, each line about two miles long, and all the lines converging together in the neighborhood of a power-house, would, on the foregoing basis of calculation and a total load of 1,500 amperes, only give a collected pipe transmission at the point of convergence of 5.82 amperes, which is much higher, except in one or two special cases, than the writer has been able to find by tests carried out in the case of a city in which the assumed case practically represents the actual conditions that existed at the period during which the tests were made. The calculations, which have been given, though, are only hypothetical, but it may be taken for granted that they come, approximately, close to the truth.

CONCLUSIONS.

General.

It is reasonable to conclude, therefore, that though a transmission medium may show no drop along a considerable length of it and is, therefore, not acting as a transmission medium longitudinally it may be acting as a considerable transmission medium transversely. Transverse stray transmission, therefore, plays a more important part in the general question at issue that has been generally supposed; and it may be defined as the stray transmission which takes place from the top to the bottom of the pipes or, "vice-versa," from the bottom to the top of the pipes. In the former case, as stray transmission would enter at the top and leave at the bottom of the pipe, the bottom of the pipe would be liable to electrolytic corrosion; while, in the latter case, as the stray transmission would enter at the bottom and leave at the top of the pipe, the top of the pipe would be liable to electrolytic corrosion.

" Non-Danger " Area.

When transverse stray transmission takes place from the top to the bottom of pipes the taking of potential readings would, by the orthodox method of conclusion, lead to the decision that the area in which the readings were taken was a non-danger area; and thus the finding in several cases of pitted pipes in a so-called non-danger area may be satisfactorily explained by the assumption that the portion of the amperage transmitted by the earth-return is partially transmitted between the "Soil" and the "Earth" by means of pipes laid close to the rails. Unfortunately, this transverse stray transmission takes place in the outlying sections of a traction system in which no method of "pipe-drainage" can be adopted. Fortunately, however, the load is light in these outlying sections and any damage which results can almost invariably be traced to localized points and as due to abnormal or what may be termed special conditions. The cure is to so treat the abnormal conditions as to render pipes, etc., at these points immune, which is by a no means difficult task to one who is well-informed in regard to the various factors controlling the situation.

Danger Area.

Transverse transmission at points in the neighborhood of where the tracks converge at the power-house, which is usually the danger area defined by potential readings, does not lead to any apparent contradiction of the finding that such is a danger area; and to render the pipes in this area immune is a simple task. For if the generators in the power-house be insulated from "Earth" in the power-house and their low-voltage side be connected by insulated cables to suitable track points (chosen so that these points will be, practically speaking, equi-voltage points—arbitrary zero points), and the loss of voltage (drop) on these insulated cables be, say, 15 volts, then a couple or so of hundred feet of insulated cable laid alongside of the pipe-line and connected to the pipes about every fifty feet can be connected by an insulated cable to the low-voltage side of the generators, the cable being of such size that the loss of voltage (drop) on it would be about 12 volts. By this method not only will the pipes be drained but they will also be lower in voltage than the contiguous rails. For stray transmission must find its home-quarters by means of some medium; and if no other one is provided this medium will be the rails in the neighborhood of the power-house or point of track convergence; where, if the accidental transmission agents, (pipes, etc.), are in close proximity to the track and the character of the soil is favorable, electrolytic corrosion will result.

IX.

Conclusions

ELECTROLYTIC CORROSION—PREVENTION.

General Advice.

The author's advice may be given in concrete form as—Do everything possible to prevent assisting earthed conductors to collect stray transmission. Do everything possible to collect all stray transmission in earthed conductors at a lower voltage than the voltage of contiguous rails. Do everything possible to keep each and every portion of the return in a first-class condition—a bad return system costs considerable money every year in the form of wasted power. For in any centralized system of electric traction, such as that of a city, plenty of insulated return copper is an A No. 1 investment for the traction company.

Pipe Protection.

Summed up, electrolytic corrosion of pipes due to grounded transmission mediums can be made a negligible factor by:—

First:

Good condition of bonding.

Second:

Special long bonding at all special work.

Third:

Insulation of generators from ground in power-house—this includes the connections between the generators and the switchboard.

Fourth:

Insulation of all sufficient auxiliary return copper between switchboard and equi-voltage points—this includes pipe drainage copper.

Fifth:

Removal of all bond connections between rails and other earthed conductors such as pipes, cable sheaths, etc., only connections permissible being to pipe drainage and insulated return cables.

Sixth:

Treatment of bad local conditions at outlying dangerous points.

Cable-Sheath Protection.

As for the protection of cable sheaths, which is more important to many traction interests than to electric light and telephone interests, the best advice the writer can give and has been constantly giving for years is "Don't." This, in so far as the question of bonding is concerned. What should be done is to run an insulated "stray transmission cable" in a duct by itself. To this cable ought to be bonded, in each manhole, all the cable sheaths, the connection between the bonded sheaths and the insulated "stray transmission cable" being by means of an insulated jumper. To drain the "stray transmission cable" it ought to be connected to the low-voltage side of the generators in the power-house, but not to the pipe drainage cable.

PERSONALITIES.

Municipalities.

It is not only the privilege, but also the duty, of municipalities to insist that electric traction companies adopt a satisfactory return system and so maintain it, when an earthed return is used; but this state of affairs ought to be obtained by a logical treatment of the question at issue—not by adopting the policy of a nagging woman.

Traction Interests.

It is the duty of traction interests to install a satisfactory return system when operating with an earthed return; and to do so constitutes a wise and good financial policy.

The Operating Engineer.

It is a foolish act on the part of an operating engineer to allow himself to become jealous of an electrolytic expert; for the expert is no more an operating engineer than the operating engineer is a designer, constructor and expert—to be an operating engineer one must (in the main) run in ruts, while to be an expert one must (in the main) keep out of ruts.

The Lawyer.

Is it necessary to inform the modern lawyer that "law" is intended, fundamentally, not only to obtain justice for one's client but also for the opponent of one's client? Let us trust that it is not.

The Expert.

To the embryo expert, the author kindly says, "Don't think that to be an expert is to lie on a bed of roses." For to be an expert one must never prevaricate or attempt to make facts out to be other than what they are. For the brain cells of the prevaricator become perverted in their action (motion) in time, and thus lose the ability to work correctly. And he whose brain cells cannot work correctly is not and cannot be an expert. Again, an expert is like the wheat between the millstones whereby others obtain the flour and precious little of himself is left but the husks.

The Author.

As to the author, he may say, almost in the words Victor Hugo used when he wrote on January 4th, 1822, to his fiancé, Adèle Foucher:

It is true that he has not invariably shown a very profound respect for several of the opinions of the general run of men, though his consciousness does not tell him that he is better than they are, but that he is different from what they are, and this is sufficient for him.

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* "The Love Letters of Victor Hugo" (translated by Elizabeth W. Latimer).

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