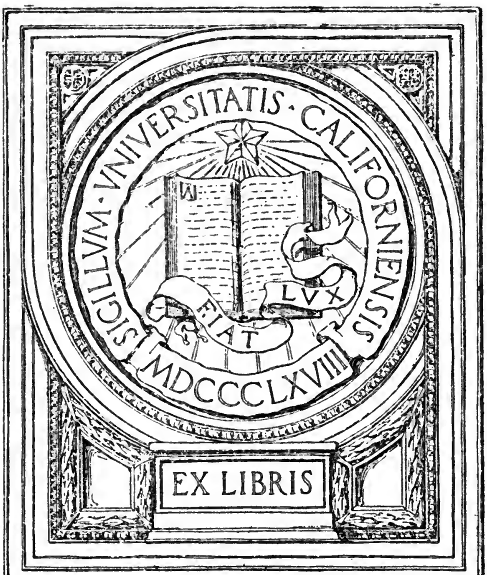
A PRELIMINARY REPORT

Prepared for Submission to its Principals

BY

THE AMERICAN COMMITTEE ON ELECTROLYSIS

1916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BY

THE AMERICAN COMMITTEE ON ELECTROLYSIS

APPOINTED BY

National Engineering Societies

and other

Interested Associations and Corporations

(PRINTED—NOT PUBLISHED)

This preliminary report is intended to include only statements of fact. It does not attempt to draw conclusions or to make recommendations or to discuss questions of law.

NEW YORK CITY

October, 1916

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PREFACE.

Those familiar with the history of the electric railway industry in the United States in the early 90's and subsequently for a decade, will recall the great rapidity with which the electric railway was developed and the litigation that resulted between the gas and water companies and the electric railway companies over the introduction into the field of the electric railway using a grounded return circuit. The utility companies whose properties were threatened with damage from electrolysis due to these grounded return circuits of the railway companies, attempted by all legitimate means to prevent the acceptance of the grounded return circuit, with the result that in one or two cases,—for instance, in the city of Cincinnati, a complete metallic overhead return circuit was adopted and is still in operation, but the electric railway operated with a grounded return circuit in connection with the overhead trolley became the standard, and rapidly spread throughout the country, and still remains the standard for electric traction systems.

At first when the electric railway systems were small, and light cars were used, the quantity of current flowing through the rails was not large, and the possibility of damage from electrolysis was comparatively small, but as the systems were extended and the weight and number of cars greatly increased, the problem became much more serious, and began to demand special attention. It is only within the past four or five years that the subject has been sufficiently well understood by engineers generally to make it probable that their opinions could be made to agree upon standard methods for the prevention or adequate mitigation of electrolysis.

At the present time, due to the fact that the grounded return circuit system has been so long established and so extensively adopted, with the result that millions have been invested in copper for supplemental rail return circuits, the engineers now endeavoring to seek a solution of the question find themselves confronted with the problem not only how best to design and install a new system to prevent damage from electrolysis, but also what can be done with the electric railway systems as they exist in cities today.

While recourse to the courts has always been open, the proving in court of the precise amount of damage that has been occasioned by electrolysis, as distinct from other causes, and accurately proportioning such damage between various electrical companies, has made the fixing of responsibility extremely difficult. In view of this unsatisfactory condition it was thought best by the National Societies representing those connected with the various utilities involved to take up the subject comprehensively and endeavor, if possible, by co-operation among themselves and with other interested associations and corporations to gather and classify information, and if then found feasible to agree upon and recommend methods which without being financially prohibitive will nevertheless practically eliminate damage from electrolysis.

The American Institute of Electrical Engineers with this object in view invited the following bodies to officially appoint representatives to serve upon a committee for which the name The American Committee on Electrolysis was finally adopted:

American Electric Railway Association.
American Gas Institute.
American Institute of Electrical Engineers.
American Railway Engineering Association.
American Telephone & Telegraph Company.
American Water Works Association.
National Bureau of Standards.
National Electric Light Association.
Natural Gas Association.

The first meeting of the Committee was held in the Directors' Room, American Institute of Electrical Engineers, 33 West 39th Street, New York City, May 27th, 1913, to make preliminary arrangements, and the second meeting held at the same place on February 25, 1914, resulted in the selection of a permanent chairman and secretary, and the appointment of the various sub-committees.

The result of the work of these sub-committees is embodied in the various sections of the accompanying report.

Owing to the complexity of the subject and the need for thorough discussion in the several technical bodies, and for further investigation by the interests involved the Committee has thought best not to attempt to issue a final report at the present time, but has endeavored to present the subject in this preliminary report by such statements of fact as its members can, at this time, unanimously agree upon, with the expectation that, after the consideration of these statements of fact by the bodies whom the members of this committee represent, and such further investigation as may be necessary by the Committee, a report will ultimately be prepared, embodying principles, rules and recommendations which will form a basis for solving this complicated problem.

New York City,
September 21st, 1916.

PRELIMINARY REPORT.

THE AMERICAN COMMITTEE ON ELECTROLYSIS.

GENERAL INDEX.

IV: EUROPEAN PRACTICE:

I. PRINCIPLES AND DEFINITIONS.

A. ELECTROLYSIS IN GENERAL.

1. Electrolysis is the process by which *chemical changes are caused* by an electric current, independent of any heating effect.

> NOTE. These changes usually occur in a water solution of an acid, alkali or salt. By the passage of an electric current through it, water (containing a trace of acid) is decomposed into hydrogen and oxygen, copper is deposited from a solution of copper sulphate, silver from solutions of silver salts. Electroplating, electrotyping, and refining of metals by electrodeposition are useful applications of electrolysis in the arts. Electrolysis is involved in the charge and discharge of storage batteries, and in the operation of primary batteries.
>
> In order that electrolysis may occur, the following conditions must be present:
>
> (a) There must be a flow of electric current through a conducting liquid from one terminal to another;
>
> (b) The conducting liquid must be a chemical compound or solution which can be altered by the action of the electric current.

2. Electrolyte, Electrode, Anode, Cathode. The *electrolyte* is the solution (or fused salt) through which the electric current flows; the conducting terminals are the *electrodes*; the terminal by which the current enters the solution is the *anode*; the terminal by which it leaves is the *cathode.*

> NOTE. The chemical changes caused by the current may affect both the electrolyte and the electrodes. In the case of a solution of copper sulphate with copper plates as electrodes, copper is removed from the anode by the current and carried into solution; an equal amount of copper is deposited upon the cathode. In general, the metal travels with the current toward the cathode.

3. Amount of Chemical Action. (*Faraday's Law*). The amount of chemical action taking place at the anode and also at the cathode (as expressed by Faraday's law) is proportional to (1) the strength of current flowing, (2) the duration of the current, and (3) the chemical equivalent weights of the substances.

NOTE. Otherwise expressed, the quantity of metal or other substance separated is proportional to the total quantity of electricity passing and the electro-chemical equivalent of the substance or substances concerned. The electrochemical equivalent of a metal is proportional to its atomic weight divided by its valence. Faraday's law is so exactly realized in practice under favorable conditions that it is used as the basis for the definition of the international ampere, one of the fundamental electrical units.

4. Cause of Current Flow. The current flowing through the electrolyte may be due (1) to an external electromotive force or (2) to the *difference of potential* due to the use of electrodes of different materials or to solutions of different concentrations.

NOTE. The first case is illustrated by electrolysis of dilute sulphuric acid using two lead plates and an external battery; the second by the electrolysis of the same solution using a zinc and a copper plate, which touch each other inside or outside the solution. The first occurs in charging a storage battery; the second in the discharging of a primary battery or a storage battery.

5. Electrolysis by Local Action. Instead of two plates of different metals the same result may follow with *one plate if* it is chemically impure or otherwise heterogeneous, when immersed in dilute acid.

NOTE. Such a plate excites local currents and a loss of metal occurs at all the anode areas. This *local action* causes impure zinc to dissolve rapidly in a solution which has no action on pure zinc.

6. Anodic Corrosion is the term applied to the loss of metal by electrolysis at the anode.

NOTE. When iron is anode the iron is carried into solution by the current, the first product being a salt of iron, the nature of which depends upon the character of the electrolyte. In dilute sulphuric acid, ferrous sulphate is formed, in hydrochloric acid, ferrous chloride, etc. These first products of the electrolysis are frequently modified by *secondary reactions*.

7. Secondary Reactions are the chemical changes which occur at or near the electrodes, by which the primary products of electrolysis are converted into other chemical substances, and are sometimes followed by other reactions.

> NOTE. Ferrous hydroxide formed by the union of iron with hydroxyl ions set free at the anode, is subsequently converted into iron oxide due to the reactions with oxygen dissolved in the electrolyte. When lead is cathode in an alkali soil or solution, the alkali metal (such as sodium or potassium) reacts with water at the cathode and forms alkali hydroxide, setting free hydrogen. This hydroxide may (especially after the current ceases) react with the lead chemically and form lead hydroxide, which in turn may combine with carbon dioxide, forming lead carbonate.

8. Cathodic Corrosion is the term applied to the corrosion due to the secondary reactions of the cathodic products of electrolysis, as described in the preceding paragraph. The metal of the cathode is not removed directly by the electric current but may be dissolved by a secondary action of alkali produced by the current.

> NOTE: The anodic corrosion is more common and more serious; cathodic corrosion, however, sometimes occurs on lead and other metals that are soluble in alkali. Cathodic corrosion never occurs in the case of iron.

B. ELECTROLYSIS OF UNDERGROUND STRUCTURES.

9. General. In the electrolysis of gas and water pipes, cable sheaths, and other underground metallic structures, and the rails of electric railways, the moisture of the soil with its dissolved acids, salts, and alkalis is the *electrolyte*, and the metal pipes, cable sheaths and rails are the *electrodes*.

> NOTE. Where the current flows away from the pipes, the latter serve as anodes and the metal is corroded. Metal or gas or alkali, according to the nature of the soil, will be set free at the cathode.

10. Self Corrosion is the term applied when a pipe or other mass of impure or heterogeneous metal buried in the soil is *corroded due to electrolysis by local action.*

> NOTE. This is called "self corrosion" because the electric current originates on the metal itself, without any external agency to cause the current to flow. Self corrosion may also be due to direct chemical action.

11. Acceleration of Local or Self Corrosion. Self corrosion is accelerated by the presence of *acids* or *salts* in the soil water which lower its resistance as an electrolyte, and also by *cinders*, *coke* or other conducting particles of different electric potential which augment the local electric currents. In the latter case the metal need not be heterogeneous.

> NOTE. A pipe may be destroyed in a relatively short time by self corrosion or local action if buried in wet cinders or in certain soils.

12. Coefficient of Corrosion. The coefficient of electrolytic corrosion, (sometimes called corrosion efficiency) is the quotient of the total loss of metal due to anodic corrosion (after deducting the amount of self corrosion if any) divided by the theoretical loss of metal, as calculated by Faraday's law, on the assumption that the corrosion of the anode is the only reaction involved.

> NOTE. In practice it is found that the coefficient of corrosion varies widely from unity, being sometimes as low as 0.2 and sometimes even above 1.5, but commonly between 0.5 and 1.1.

13. Anodic and Self Corrosion. Anodic corrosion due to external currents and *self corrosion* due to local action may occur simultaneously, and the *former may accelerate the latter.*

> NOTE. Hence the corrosion due to a given current plus the increased self corrosion induced by that current may give a greater total corrosion than called for by Faraday's law. This explains how the coefficient of corrosion may exceed unity.

14. Passivity is the name given to the phenomenon in which a current flows through an electrolyte without producing the full amount of anodic corrosion which would occur under normal conditions.

> NOTE. This restricted definition of passivity has regard only to its effect in electrolysis. Many conditions affect the degree of passivity attained, an initial large current density being favorable to it. Plunging iron into fuming nitric acid renders it temporarily passive. A satisfactory explanation of passivity has not been given.

15. Polarization Voltage (sometimes called polarization potential) is the temporary change in the difference of potential between an electrode and the electrolyte in contact with it due to the passage of a current to or from the electrode. This change in potential difference, is due to the change in the conditions of the surface of the electrode or change in the concentration of the electrolyte (or both), and under some conditions is approximately proportional to the current flowing, but in many cases is not so proportional. The magnitude of the polarization voltage also depends on the material of the electrode, the nature of the electrolyte and the direction of the current.

16. Alternating or Frequently Reversed Direct Currents. If alternating currents (or frequently reversed direct currents) flow through the soil between pipes or other underground metallic structures, the metal removed during the half cycles when a pipe is anode may be *in part replaced* when it is cathode. Hence, the total loss of metal on a given pipe is less than one-half of what it would be if the pipe were an anode with direct current of the same average value in the case of frequently reversed direct current and in the case of alternating current at commercial frequency it is less than 1% and in most cases negligible. (See Section 52.)

NOTE. In slow reversals of current, the recovery effect is less, but the loss will be less than with direct current continuously in the same direction (excepting possibly where the phenomenon of passivity may affect the result).

17. Action on Underground Metallic Structures. Faraday's Law applies to electrolysis of metallic structures in soil as elsewhere, the total chemical action being proportional to the average current strength and the time the current flows and to the electrochemical equivalent of the metal or other substances concerned. Although local action and passivity affect the loss of metal and so apparently modify Faraday's law, it is still true that the total chemical action resulting from the current flow is proportional to the total current when local currents are included.

NOTE. Sometimes this chemical action is concerned only with corroding the anode; sometimes it is concerned with breaking up the electrolyte, as when the anode is a noble metal or in the passive state (as iron and lead sometimes are); sometimes both these effects occur.

The theoretical loss of lead from a lead pipe or cable sheath is 3.7 times as great as that of iron (ferrous) from an iron pipe due to the same current because of the larger electrochemical equivalent of lead.

18. Stray Current. If the railway return utilizes the grounded rails of the tracks, part of the current will flow off the rails or other grounded returns and return through other paths; the current observing the law of divided circuits; *i.e.* the current flows through all possible paths in parallel, the strength of current in each path being inversely proportional to its resistance. This statement excludes the effect of polarization on rails and underground structures, which in some cases is appreciable.

19. Electrolysis Mitigation. The two primary features of electrolysis mitigation are (1) the reduction of the flow of current through the earth and the metallic structures buried in the earth, (2) the reduction of the anode areas of such structures to a minimum, where the current is not substantially eliminated in order to reduce the area of destructive corrosion as far as possible.

NOTE: The current in the underground metallic structures will be decreased, other conditions remaining the same, by (1) increasing the conductance of the return circuit, (2) increasing the resistance of the leakage path to earth, (3) increasing the resistance between the earth and the underground metallic structures, (4) increasing the resistance of the underground metallic structures.

The anode areas of the underground metallic structures will be decreased, other conditions remaining the same, by providing suitably placed metallic conductors for leading the current out of the underground structures so that the flow of the current directly to the earth shall be minimized. This will change a portion of the anode area to cathode.

20. Electrolysis Surveys. A term applied to investigations made to determine the condition of grounded metallic structures and the soil in which they are imbedded and of the overall drops, potential gradients, local potential conditions, current densities, etc. in the railway tracks, or other grounded metallic structures, and positive and negative feeders connected to them to determine what conditions tending to produce damage exist.

21. Overall Potential Measurements. Overall potential measurements show the difference in electric potentials between points in the tracks at the feed limits of the station and the point in the tracks which is lowest in potential, and are obtained by means of pressure wires and indicating or recording voltmeters.

NOTE: The pressure wires may be telephone or other wires utilized temporarily, or wires permanently installed for the purpose.

22. Potential Gradients. The potential gradient is the rate of change of electric potential along the rails of a track or other grounded structure in the earth, and is usually expressed in volts per thousand feet or volts per kilometer.

23. Positive and Negative Areas. Positive areas are those areas where the current is in general leaving the pipes or other underground metallic structures for the earth. Such areas are often called *danger areas*.

Negative areas are those areas where the current is in general flowing to the pipes or other underground metallic structures.

NOTE: As the current often flows from one underground metallic structure to another, it is evident that within a positive area there are local negative areas and vice versa. Hence the terms are applied somewhat loosely, and according to which condition predominates.

Besides the positive and negative areas there are areas of more or less indefinite extent in which the current flow between metallic underground structures and earth normally reverses between positive and negative values. These areas are called *neutral areas* or *neutral zones*.

24. Drainage Systems. A drainage system is one in which wires or cables are run from a negative return circuit of an electric railway and attached to the underground pipes, cable sheaths or other underground metallic structures which tend to become positive to earth, so as to conduct current from such structures to the power station, thereby tending to reduce the flow of current from such structures to earth.

NOTE. Three kinds of drainage systems may be distinguished. (1) where direct ties with wires or cables are made between underground metallic structures and tracks, (2) where uninsulated negative feeders are run from the negative bus to underground metallic structures, (3) where separate insulated negative feeders are run from the negative bus to underground metallic structures, or a main feeder with taps to such structures.

25. Uninsulated Track Feeder System. An uninsulated track feeder system is one in which the return feeders are electrically in parallel with the tracks. Under such circumstances the cables may be operating very inefficiently as current conductors and as a means of reducing track voltage drop, particularly where voltage drops in the earth portion of the return are maintained at the low values usually required for good electrolysis conditions. (See Section 47 (d)).

26. Insulated Track Feeder System. An insulated track feeder system, sometimes called an insulated return feeder system, is one in which insulated wires or cables are run from the insulated negative bus in a railway power station and attached at such places to the rails of the track as to take current from the track and conduct it to the station, in such a manner as to reduce the potential gradients in the tracks and the differences of potential between underground metallic structures and rails, and so reducing the flow of current in underground metallic structures. (See section 53).

> Note. The insulated negative feeders may run separately from the negative bus to various points in the track network, or a smaller number of cables may be used with suitable resistance taps made to tracks at various places.
>
> With this system the drop of potential in the track feeders is independent of the drop of potential in the tracks.

METHODS OF MAKING ELECTROLYSIS SURVEYS.

A: GENERAL.

27. General Principles of Electrolysis Surveys. The principal measurements made in electrolysis surveys of underground structures are measurements of the potential differences between the structure tested and all other neighboring metal structures in earth, neighboring rails, and neighboring earth, and measurements of current flow on selected sections of the structural system under test. The potential difference between the structure tested and earth affords more complete information than can be secured from the results of any other practicable class of observations. The difficulties are, however, to make these measurements so as to obtain the true potential difference between the earth and the earthed structure, and frequently also to obtain contact with earth in the immediate neighborhood of the structure tested. If an electrode is used for the earth potential measurement, not consisting of the same metal as the structure tested an error may still be introduced due to difference in the polarization potential of the two electrodes. A non-polarizable electrode has been devised by Dr. Haber, as described later in this report, but it has been used only to a very limited extent in this country. On account of the difficulties of making earth potential measurements, measurements of the potential differences between the structure that is being surveyed and neighboring metal structures are much more generally made.

Measurements of stray current flowing in selected sections of any structural system are practicable if a suitable length of the structure can be made accessible. By comparison of such measurements conclusions can be reached as to the areas in which stray currents are being taken from or delivered to the earth and as to the amounts of current which are concerned in these exchanges. Measurements of this character usually cannot be made on sections so close together as to give for many points definite values for the current flowing to or from earth on account of the high cost of the necessary excavations and permanent replacements. We have therefore included a description of the "earth ammeter" which has been used abroad, and to a limited extent also in this country, for obtaining direct measurements of current flow in the earth.

A survey of the earthed structures which are liable to electrolytic corrosion by stray currents consists in making such observations relating to their electrical condition as may determine the route followed by the stray current and its degree of concentration, thereby permitting deductions to be made relative to the extent and the intensity of the electrolytic injury to which the structures may be subjected. While measurements of potential are most frequently made (to such an extent that the term "Potential Survey" is often applied to this work), it should be borne in mind that the real object of the survey is to determine where current may flow from structure to earth or from earth to structure and the magnitude of the current flowing for each of the smallest sections into which the structure can practically be subdivided.

In discussing methods of survey, the measurements of potential and current peculiar to each class of earthed structures will first be described, together with any special observations or precautions to be taken. A discussion of the measurements of a general nature common to all classes of structures will then follow. Measuring instruments and other apparatus employed in connection with this work will be described in detail in the section devoted to apparatus.

28. Electric Railways. Before making measurements relating to an electric railway system the available information as to its extent, its construction features and particularly the arrangement of its earthed return circuit and the connections thereto should be collected. The best available maps should be procured and all information pertinent to the electrolysis investigation recorded, either by annotation on a suitably arranged map, or in some other convenient form. All electrical connections made for any purpose with the rails or other parts of the return circuit should be noted with special care, and the location of any structures to which connection is thus made ascertained and recorded.

The principal measurements to be made upon the grounded return system of an electric railway are as follows:

1. Potential differences between the point of lowest potential on the tracks, and selected points on the tracks throughout the feeding district of the station under observation.

2. Potential gradient measurements along the railway tracks to determine the difference of potential between points on the track separated from each other by distances of from 1,000 to 3,000 feet.

3. Differences of potential between all points where negative feeders or other connections between bus-bars and rail return make contact with track; also differences of potential between these points and the station bus-bar.

4. Currents carried by each separate connection between bus-bar and rail.

For most of the potential measurements listed above, it is necessary to have available insulated wires connected with all points on the railway return system, whose potential relations are to be determined, all of these insulated wires being brought to some common point so that measurements may be made between them. Where pilot wires have been installed by the electric railway, many, if not all of the points at which it is desired to make tests will be accessible without the necessity of any special preparations. Where pilot wires are not available or where it is desired to reach points not included in the pilot wire system, the most economical plan will be to procure the use of any available circuits found in the local telephone distribution system. Short lengths of insulated wire will need to be run to connect such circuits with the tracks and the testing circuits thus established can readily be brought together at some common point for measurements between them. Where neither of the above alternatives is available, wires can be installed in some temporary manner over available pole line routes to connect with the points whose potentials are to be observed. Such wires should be insulated from earth except at the point where they connect with the tracks.

When the testing circuits are established, the required potential measurements should be obtained by connecting to a voltmeter the wires leading to the two points where difference of potential is to be determined. The voltmeter should be kept in circuit and under observation for a time sufficient to insure that the normal fluctuations of the railway load have been accounted for. When long time observations of the potential difference between two points are desired, a recording voltmeter should be employed. If circuits to a sufficient number of points have been installed, the measurements of potential gradient in the tracks may be taken by connecting the proper wires at the central point to the voltmeter. If the requisite number of pressure wires for gradient tests is not available, these measurements may be obtained by carrying a suitable length of insulated wire along the track and connecting it through a voltmeter to the track at the two points between which the gradient is to be measured.

Measurements of current flowing in negative feeders or in other connections to the track return can be taken by inserting an ammeter in the circuit to be measured, when this is possible, or by taking the voltage drop along some accessible section of the connecting lead, which is sufficiently uniform in dimensions to permit of a ready calculation of its resistance. It is important that all such measurements of current should be taken either simultaneously with measurements of potential difference between the bus-bar and the track end of the connection, or under such conditions as to permit of their accurate correlation with the potential observations. A station load curve should also be obtained on account of the information which it gives as to the characteristics of the power supply.

Measurements of rail bond resistance are not necessarily a part of the work to be done in an electrolysis survey. It is, however, occasionally necessary in connection with a survey to test the resistance of particular rail bonds in order to obtain data necessary for the explanation of results obtained in making some of the regular measurements. When such tests are made, the fall of potential across the joint in the rail should be observed simultaneously in comparison with the difference of potential for some short measured length of the adjacent rail. If one of the special rail bond testing devices is not available for this work, two voltmeters can be employed and read simultaneously, or one voltmeter can be connected with a quick acting switch and employed so as to secure practically simultaneous observations. This latter method may give unreliable results unless a large number of readings are averaged.

29. Earthed Piping Systems. Before tests are made to determine the electrolytic condition of any piping system, all available information as to its extent and the characteristics of its construction should be collected and studied. The best available maps of the system should be procured and any special information of importance in connection with an electrolysis survey not noted on the maps, such as the metals of which the pipes are composed, the location of insulating joints, the relative locations of other piping, and cable systems, the location of electric railway tracks and return circuits, etc., should either be recorded upon them or arranged in some convenient form for reference.

The observations which should systematically be taken in examining a piping system are as follows:

1. Difference of potential between piping system and electric railway rails, other piping systems, cable systems, metal bridges, steam railway rails, etc., at points where these cross the piping system or come in close proximity to it. (Potential survey).

2. Measurements of potential difference between adjacent hydrants, or adjacent drip or service connections. (This will serve to give the direction of the current flowing in the pipe line and some rough indications of its amount).

3. Measurements of current flowing upon exposed sections of pipe. (Current survey).

4. Difference of potential between points on the piping system and the adjacent earth if contacts with earth can be obtained.

To make a potential survey, potential differences between the underground pipes and rails are usually measured at a number of points along every street where there are pipes and electric railway tracks. Where there are other underground pipes and lead-sheathed cable systems, it is desirable to make simultaneous measurements of potential difference between the piping system being surveyed and the neighboring pipe and cable sheaths. It is desirable to make all of the measurements of potential difference at any one point simultaneously between all structures tested. Contact with the underground pipes for these potential measurements may be made by means of service pipes, hydrants, or drip connections. The connections used for the potential measurements may be tested for electrical continuity by means of an ammeter connected between the contacts with a dry cell in series if necessary.

Measurements of potential difference between adjacent test points on the piping system should also occasionally be taken. As the resistance of pipe joints is usually not uniform, only an approximate idea of the current flowing can be obtained in this manner. The principal object of this test is to obtain an indication of the direction of the flow of current.

It is therefore desirable to make a rather large number of these tests at quite frequent intervals, since the results may be interpreted only in a general way; individual tests may be expected to vary widely, and in some cases they may even conflict. This test may be made for shorter intervals and in greater detail, where some sudden change of potential difference to earth or neighboring structures has been observed. Owing to the uncertainties as to resistance of joints it is best not to attempt to translate these voltage readings into terms of current. They may, however, be used in comparisons to assist in fixing the points for more accurate measurements of current as described in the next paragraph.

When the potential observations have been completed and transferred to a map or in some other way assembled for study, consideration should be given to them with a view to determining what parts of the piping system appear likely to be receiving substantial amounts of current from earth or passing substantial amounts of current to earth. The neutral sections of piping between positive and negative potential zones should also be located. With this information at hand sections of the piping system should be selected both in the positive and negative zones and in the neutral area at which excavations can be made and determinations of the current flowing in the pipes obtained. In selecting points for excavations, preference should in general be given to the main piping routes, but attention should also be given to any branch lines which appear likely to be receiving or delivering relatively large amounts of current. Any cases where sections of the system located within the "negative area" give positive readings to earth, should also be given preference in this study.

The method of measuring current consists in determining the fall of potential along a measured length of pipe of known dimensions. For the purpose of this measurement it will generally be found advisable to attach insulated wires permanently to the pipe and to carry them to some suitable point underneath the sidewalk from which they may be led up to the surface to terminate in service or other suitable boxes so as to be available for measurements of current in the future after the excavation has been filled. (See Fig. 1.) Tables giving the resistances of unit lengths of pipe of different diameters and materials are attached

DIAGRAM SHOWING
PIPE CURRENT TESTING INSTALLATION

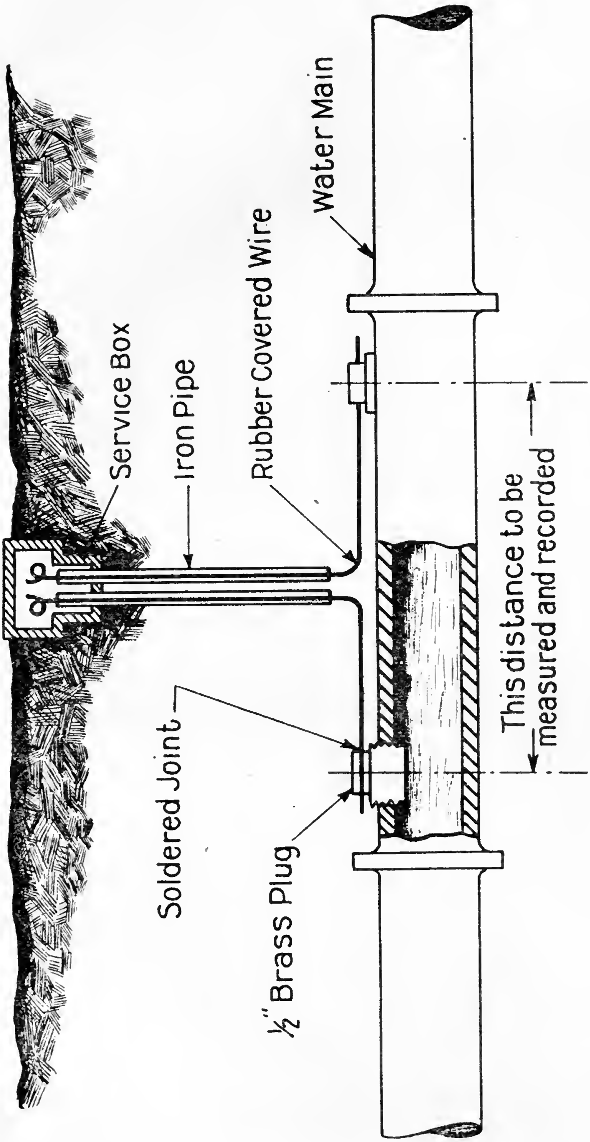


Figure 1

to this report. (See Appendix Tables 9-10). The current flowing in the pipe may be obtained by computation from the observed drop of potential and the unit resistance for the class and weight of pipe.

In addition to the observations made upon the piping system, careful attention should be given to the condition of the service pipes to buildings, particularly in locations where the services cross other piping systems, cable systems, etc. The potential between these service pipes and earth and between the service pipes and the other earthed structure crossed should be determined. It will not be within the scope of the usual survey to determine the condition of all service pipes in the area covered, but it is desirable that some of the services be tested in order to ascertain whether there is any serious tendency towards the local electrolytic corrosion of service pipes. When buildings are entered for the purpose of testing service connections, tests of potential should always be made to any other service pipes or cables which enter the same building, in order to detect cases where one structural system is making contact with the other. Current measurements may also conveniently be made on service pipes in buildings, since the pipes are exposed. Such tests should be made frequently, as they often reveal an interchange of stray current between piping systems which may be in contact in the building.

30. Underground Cable Systems. Before tests are made to determine the electrolytic condition of any cable system, all available information as to its extent and the characteristics of its construction should be studied. Available maps of the system should be procured and any special information of importance in connection with an electrolysis survey not noted on the maps, such as the metals used for the armor or sheathing of cables, the location of drainage connections, insulating joints and other protective devices, the relative locations of other cable systems and of piping systems, the location of the electric railway tracks and return circuits, etc., should either be recorded by annotation upon them or arranged in some convenient form for reference.

The observations which should systematically be taken in examining the cable system are as follows:

1. Difference of potential between the cable system and electric railway rails, other cable systems, piping systems,

metal bridges, steam railway rails, etc., at points where these cross the cable system or come in close proximity to it.

2. Difference of potential between points on the cable system and the adjacent earth.

3. Difference of potential between cables in the same subway system where they are not cross bonded.

4. Current flowing upon the cables.

In making surveys the potential of the cable with respect to the adjacent earth should always be determined at each testing point. In original surveys the greatest practicable number of testing points should be utilized. In some systems it will be desirable to test at every manhole, but in extensive networks of power cables it will ordinarily be sufficient to test at less frequent intervals in many districts, if tests are made at shorter intervals in the most important places. The potential difference between the cable and rails in the same street should also be determined, but in cases where the street railway rails parallel the cable route for a considerable distance, such tests may be made less frequently. If pipes or other earthed metallic structures run close to the cable system at the point of testing, it is desirable that the potential difference between the cable system and the other structure be determined, provided an electrical connection can be made, *e.g.*, through a hydrant, etc.

Tests to determine the direction and amount of stray current flowing on the cable sheaths should be made at appropriate intervals. In fairly simple cable systems, with few laterals, it may be sufficient to make these tests at comparatively infrequent intervals, such as every fifth manhole. In complicated networks, however, such as power distribution systems with many branches and service connections, it will generally be desirable to test more frequently. The current flowing on the cable sheath is to be calculated from the observed fall of potential over a measured length of sheath, and the known resistance of this length of sheath. A table for determining current on lead cable sheaths from voltage drop in measured length of sheath is appended. (See Table 11.)

In the course of the survey, measurements should also be made of the current flowing in any drainage connections or in any accidental connections which connect the cable system with the electric railway return if any such exist. In case insulating joints have been inserted to protect any parts of the cable system from electrolytic corrosion, measurements of the potential difference between cable sheath and earth should be made at each side of the insulating joint, and also of the difference in potential across the joint.

In a preliminary study it should be ascertained whether it is the local practice to insulate from the main cable system those branches which enter buildings. When such branches are not insulated from the main system, tests of difference of potential should be made, between the branch cable and any pipes or other cables which may enter the same building. From such tests it may be ascertained whether there are accidental contacts between the cable system and other earthed structures within buildings, and if any such are found in a portion of the total number of installations, a conclusion can then be reached as to the desirability of checking the conditions in all buidlings entered. In localities where it is the practice to insulate from the main system cable branches entering buildings, the possibility of defective insulation should be checked by measuring the potential difference between cable inside of the building and cable outside at some point beyond the supposed location of any insulating joint. Tests for differences of potential between the branch cable and other metal structures within a building can be omitted in case the insulating joint is found to be in good condition.

The condition of the bonds installed to equalize the potential of the cables entering such manhole should be observed and noted. If bonds are lacking, or if it is suspected that the condition of any bond is faulty, observations of the difference of potential between the cables should be taken and recorded.

31. Bridges, Buildings and Other Earthed Structures. Through the study of maps, etc., collected as preparatory data for surveys of piping and cable systems, information will presumably have been secured concerning the locations, and some, at least, of the structural characteristics, of the highway and railway bridges located within the area to be studied. The locations of steam railway tracks will similarly have been obtained.

In making electrolysis surveys of bridges, measurements of potential to earth should be made at each end of the metal structure. In case the bridges are crossed by electric railway tracks, piping systems or cable systems, measurements should also be made from the metalwork of the bridge to these structures to determine whether there is any difference in potential between them. Where the metalwork of the bridge structure, piers, or other intermediate supports makes contact with earth or with water, measurements of potential difference to earth or to water also should be made. The observer should follow up closely any indication of poor electrical contact between different sections of the metalwork of the bridge, or between the metalwork and any other of the earthed structures crossing the bridge which are supposed to be in good electrical contact with the metalwork.

In the course of the survey, metal frame buildings may be found in locations where it would be possible for them to collect appreciable amounts of current, either directly through the earth or indirectly through the contact of rails, pipes, or cables with the framework. If it appears that such contacts exist, measurements by the fall of potential method should be made to ascertain whether appreciable currents are flowing into the building through these contacts, if this is found to be the case tests should be made at a number of points from the building structure to ground for the purpose of determining where the current leaves the framework and whether there is any indication that appreciable damage is being done. In the case of buildings extending over a considerable area it is desirable that measurements of potentials be made from the framework to earth at a number of points, even in case no contacts are found between the metal framework of the building and other metal structures which may be carrying stray currents.

32. Steam Railway Rails. Steam railway rails, either through direct contact with electric railway rails or, in the absence of an insulating ballast, through contact with earth, are liable at times to collect and discharge appreciable amounts of stray current, and this may occur in such a manner as to be detrimental to the track rails, spikes and adjacent earthed structures. Because of this, as has already been indicated, measurements of potential to steam railway rails should be made whenever the structures that are being surveyed are in close proximity to steam railway tracks, and it is also desirable to determine directly by survey the condition of metal steam railway bridges as well as the condition of metal highway bridges. When steam railways are equipped for electric block signaling the signal battery will affect the potential of the rails. The potential due to the signaling connection is, however, practically uniform in value and can be determined through observations made at times when no stray current can be flowing. With this potential fixed, a conclusion as to the presence and amount of any potential can readily be reached.

33. General Survey Practices. All measurements, excepting 24-hour records, should be made during the period of normal load on the portions of the railway system which are suspected of being the sources of stray currents. In general, it is desirable to express the results of short time measurements in terms of "average day load" on the railway system. In localities distant from the source of railway power supply, the foregoing considerations make it necessary to take into account the presence or absence of moving cars at points beyond the testing station, especially on the tracks nearest to the structure which is being tested. In such localities the duration of a test should be extended to include at least one complete cycle of car movement, unless previous experience at other testing points in the immediate neighborhood have clearly indicated that parts of the cycle may safely be neglected. As the railway lines converge toward a common center, or as the source of railway power supply is approached, the probability of normal load condition increases but even under these conditions it is necessary for the tester to insure that the railway load conditions are substantially normal, when measurements are being made.

At a number of points observations of potential differences and of current flowing along the structure should also be made with 24-hour recording instruments and the characteristics of these currents and potentials compared with the characteristics of railway load curves. This will serve to indicate whether the current and the potential are identified with the railway source. The 24-hour averages for currents and potentials obtained at these points of measurement will also be of use in indicating what allowances should be made in the readings taken systematically at all points of the system in order to make them represent the average day conditions.

During observations of potential or current the movements of the needle in the measuring instrument should be closely watched so that the maximum and minimum readings may both be obtained as well as any change in the polarity of the potential or in the direction of the current. The observer should also bear in mind that collected results of the individual tests will be plotted on a map or otherwise compared so as to get a general idea of the conditions prevailing. When, therefore, there is reason to believe that the recorded maxima and minima are abnormal, notes should be made giving the reasons for such a belief and indicating the value which is thought to be more nearly comparable with the values obtained at other points.

In regular field survey work portable measuring instruments, will be found most suitable for the great majority of the measurements to be taken. Occasionally, however, conditions will arise under which it is desired to observe the potential or the current at some particular point for several hours and even for one or more 24-hour cycles. In the case of such long period observations recording voltmeters, millivoltmeters and ammeters will be found of great assistance and should be employed if available. Instruments of this kind are described in the apparatus section. (Sec. 35-39.)

When bodies of water or areas of swampy earth cross or are located in close proximity to earthed structures, stray current may flow from the structure to earth locally. This is particularly true if the water is brackish or salty. In case such relatively high conductive sections of the earth afford a path of lower resistance for the return of current than the structure itself, the probability of a large flow of current to earth is considerable. The flow of current from the earthed structure is not necessarily stopped when such highly conductive strata have been hidden by building over them or by filling in with surface soil. It is, in consequence, necessary to observe closely the physical geography of the areas covered by the survey and unless the observer is personally familiar with the history of the locality and the changes which have occurred, it is desirable for him to ascertain the facts from those familiar with them. If the structure under observation is accessible for tests at intervals of a few hundred feet and care is taken to make tests of potential to earth at all of these points, the presence of any condition which tends to cause the localized flow of current from the structure to earth will usually be detected. While the labor of making the survey is increased through the necessity of such frequent observations, it is preferable to include all accessible points in the original survey and to eliminate testing points in subsequent surveys when sufficient experience has been gained to indicate that greater distance between points of observation is safe.

When the electric railways in the area under investigation receive current from two or more sources of supply and there are indications that electrolytic damage is occurring at any point upon the earthed structures investigated, it may become necessary to ascertain the origin of the current causing the injury. The preliminary study of the electric railway system or systems will have included the detailed methods for distributing power, whether the trolley systems are interconnected or divided into insulated sections and whether or not all of the rails are interconnected at junctions, etc., as well as the methods of bonding and cross-bonding. If the trolley is supplied from several sources in parallel, the effect of any one of these upon the distribution of stray currents may most easily be studied in connection with the starting or shutting down of that particular source. When substations are operated only during part of the day, tests may be arranged to take advantage of this. When the substations are continually in operation, resort may be had to the method of simultaneously observing the load indicated by the station instruments, and the quantities to be measured on the structure being surveyed. Recording instruments are often useful for this purpose.

When the sources of power are not supplying the trolley in parallel but are confined to certain definite districts, a close study of the railway schedule should be made as it will frequently be possible to select some set of conditions where the current at points of observation must be coming almost wholly from one of the sources on account of the relative positions of cars, etc. Where two electric railways operate independently without connection between their trolleys but with intersections or junctions between their tracks, the situation is similar to that just described where the railway trolley is divided into insulated sections and the same methods of investigation can be followed. Where there is no connection between either trolleys or tracks of two independently operated electric railways this same method should also be followed, *i.e.*, of observing stray current conditions when one road is using considerable current in the immediate neighborhood and the other road is using little or none and comparing the observations with those obtained when both roads are using normal amounts of current in the neighborhood. It is to be noted that when two railways are without any electrical interconnections between either trolleys or tracks, the track return of either may carry stray current from the other railway and if the track return is of high conductivity it may assist materially in producing adverse electrolytic conditions on other earthed structures particularly in cases where it provides a short route between two points between which considerable potential difference exists.

The earth ammeter, previously referred to, may occasionally be found useful in checking up conditions indicated in the systematic survey observations. The construction of the device is described in the apparatus sections. If care is taken to have the plates placed perpendicular to the direction of current flow, the current density at the point of measurement may be indicated by the current flowing through the instrument. If necessary, the lines of current flow may be determined by voltage readings between test electrodes before burying the instrument.

The greatest care should be taken in placing the instrument to avoid unnecessary disturbance of the soil, in order that the flow lines may follow, as nearly as possible, their normal directions.

Whenever excavations or other exposures of pipe surfaces make it possible, measurements of the resistance of pipe joints should be made. Where the joints are of moderate resistance, that is, not so high as to prevent current flow upon the pipes, this measurement may be made by simultaneous observations of the fall of potential across the joint, and along a measured length of the pipe; the pipe joint resistance may then be expressed as equivalent length of pipe, or, by reference to tables, in ohms. These measurements are of importance in indicating the characteristics of the pipe line as an electrical conductor, in estimating the probability of corrosion at joints due to shunting, etc.

Wherever the surfaces of the earthed structures under investigation are exposed during the course of the tests, their conditions should be noted. The pitting of the metal surfaces or the presence upon them of rust or other oxidation products, or an obvious reduction in the thickness of the metal or any other evidence that corrosion has taken place, is not of itself direct evidence that electrolytic corrosion has occurred. Corrosion from any cause whatever would be expected to reduce the thickness of the metal, and the rate at which such corrosion occurred and its possibilities in the way of irregularity of attack on different portions of the surface, would determine the occurrence of pitting. Many of the products of corrosion which will be encountered can also be produced through purely chemical reactions, as well as by electrolysis. When the measurements made in the survey demonstrate that current is flowing from structure to the earth at the point where corrosion is observed, conclusions can be drawn as to the causative relation between the presence of stray current and the evidences of corrosion. Whatever the conditions found in the survey readings, the condition of obviously corroded metal surfaces should always be carefully noted, as it is, of course, always possible that at some past time stray current has been flowing from the surfaces to earth, or that some local condition has been favorable to the "self-corrosion" of the structure. Points where substantial corrosion of the structures under investigation is found, are always to be regarded as good locations for taking the samples of soil referred to in the following paragraph.

It is often desirable to gather data relative to the electrical and chemical characteristics of the soils in the area studied. As different types of soil are encountered in the course of the survey either in the making of excavations or through the observation of changes in surface conditions, samples should then be taken and their electrical conductivities determined. It is often desirable also to make chemical analysis of a number of samples of ground waters and of the water-soluble portion of soil samples secured for conductivity tests.

34. Application of Remedial Measures—Re-surveys. The survey methods described in the previous paragraphs include practically all of the work which would be done in an extensive original survey, that is, in a district where no work had been done previously. While this problem in all of its aspects has been investigated in only a few American communities, it will be found that more or less complete surveys have been made in almost any area traversed by electric railways.

The test methods described are not all of equal value for all problems; their application depends upon the particular problem under consideration. Further, many of the tests require considerable experience and technical skill in application, to avoid erroneous and misleading results. For these reasons, extensive surveys should only be undertaken by experienced investigators.

Following the completion of the original survey, a decision will be reached as to whether measures for mitigating electrolytic corrosion are necessary, and if so, what methods are to be applied. Conclusions as to the effectiveness of any protective measures should be based upon repetitions of the test made in the orginal survey. The amount of repetition necessary will depend upon the character of the protective measures adopted. Thus, general improvements in railway return circuits will ordinarily require a complete re-survey of the affected area. The installation of an insulating joint between the main line structure and a branch should, on the other hand, require little more than tests over short sections either side of the joint, to determine that the current flowing has been reduced and that no objectionable corrosive conditions have been introduced at the joint itself.

If railway return circuits are being changed, some observations of overall potentials and potential gradients will naturally be made during the course of reconstruction, to check the design upon which the work has been based. Observations should be made before installing drainage systems for cables, if necessary using available conductors temporarily to connect the cable sheath and the railway bus-bar or some other suitable point on the railway return, and the effect of drawing current from the cable system observed. The installation of such protective measures as insulating joints or insulating coverings should be carefully supervised as much depends upon the thoroughness with which the work is done.

In re-surveys after the installation of protective measures, the character of the underground structure will make it necessary to pay special attention to some particular class of observations. With piping systems and power distributing cable systems special attention should be given to the amount of stray current flowing on the structures, since a principal object of the remedial measures will have been a reduction in this current. When insulating joints have been installed tests of potential to earth from each side of the joint are required to make sure that the local flow of current to earth has not risen to an amount which will endanger the structure. Tests of stray current in the system on either side of the joint are also required to determine that the effect desired from its installation has been obtained.

When drainage connections are attached to cable systems, tests of potential to earth must be made throughout the area affected. The connection should make the cable negative to earth at all points, but only by slight amounts at or near the point of its attachment, as otherwise the cable will carry more stray current than is needed for its protection, and it becomes a source of danger to other undrained structures.

Where insulating joints or other protective measures are applied to structures buried in the earth, care should be taken to attach testing leads to be used in future surveys. Such connections will be of the same general type as the current measuring leads for pipes (See Fig. 1.).

Electrolysis surveys should be repeated at suitable intervals. In case the original survey did not disclose conditions requiring the application of remedial measures, it is still necessary to make sure that adverse conditions have not since arisen. Where protective measures have been applied, surveys are needed to make sure that the remedies remain effective and adequate The interval between surveys will depend upon the importance of the structure and upon the time required to produce appreciable damage in case a substantial change in stray current conditions occurred. The results of all such surveys should always be compared with those of previous surveys to ascertain whether changes in stray current conditions are taking place. When any substantial changes or additions are made in the electric railway plant, surveys of the earthed structures liable to be affected by the new conditions should promptly be made.

B: APPARATUS.

In this section descriptions are given of the apparatus and tools which are essentially special for electrolysis work. The tools ordinarily used for handling wires and making good contacts in electrical work will also be needed but no special description or listing of them seems to be necessary in this place.

35. Portable Measuring Instruments. The portable measuring instruments required in electrolysis survey work include voltmeters, millivoltmeters and ammeters. Separate instruments of each kind can, of course, be carried but it will usually be found more convenient to employ the special portable instruments which have been designed particularly for this work.

Two such instruments which the Weston Electrical Instrument Company manufacture for this class of work are as follows:

> Model 1, combination millivoltmeter and voltmeter, has its zero in the center of the scale and reads in both directions. Ranges of 5, 50 and 500 millivolts and of 5 and 50 volts are convenient. It is made with a specially high resistance of from 500 to 600 ohms per volt so that the 5 millivolt range has a resistance of about 3 ohms. These high resistances increase the accuracy of measurements and particularly minimize errors due to resistances of leads or contacts. Ordinary switchboard shunts provided with binding posts and adjusted for 50 millivolts may be used to make this instrument serve as an ammeter. Convenient ranges for these shunts in electrolysis work are, 5, 50 and 500 amperes.
>
> Model 56, combination volt-ammeter, has its zero in the center of the scale and reads in both directions. Ranges of 10, 50 and 500 millivolts, 5 and 50 volts and 100 amperes are convenient.

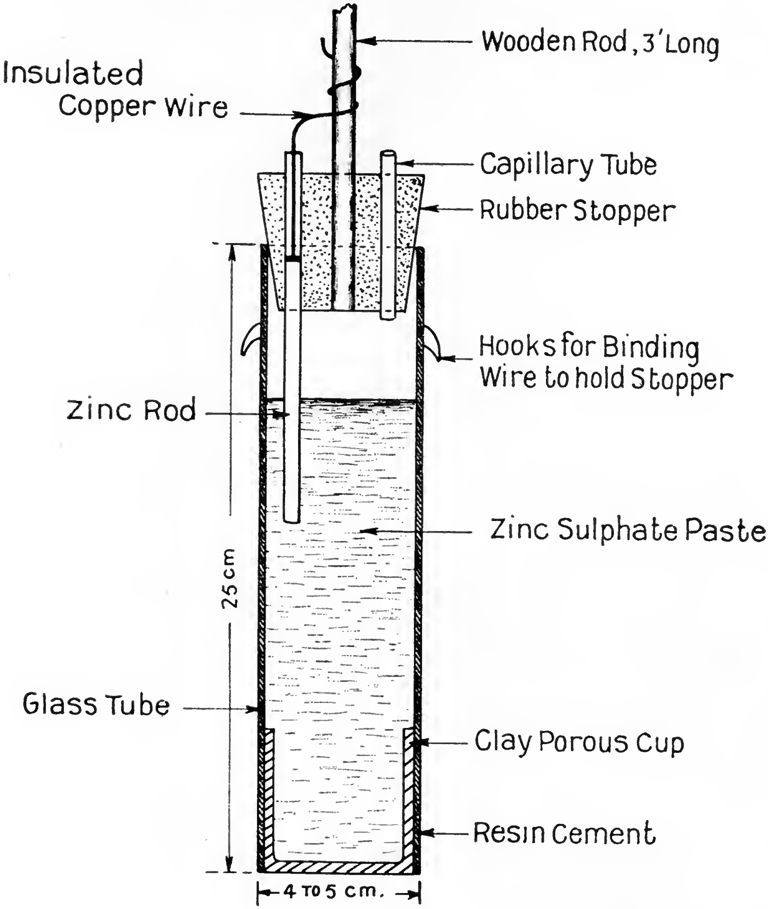
The center scale feature referred to in the description of these instruments is an important one in electrolysis work, as it is not always possible to determine in advance the direction of current or potential, and readings may also vary from positive to negative values during the making of observations at many testing points. When simultaneous readings have to be taken at two or more testing points it is important to use similar instruments at all points. If dissimilar instruments are used their periods of vibration may differ and with the fluctuating voltages and currents encountered in much of this work accurate simultaneous measurements cannot be made unless the instruments used have the same periods of vibration.

36. Recording Instruments. Recording measuring instruments are usually arranged to give 24-hour records without change of chart. By using a sensitive millivoltmeter in the recording instrument and providing it with a number of voltage ranges as well as with suitable shunts, a single instrument can be made available for taking all of the voltage and current readings required in electrolysis work. The original type of Bristol recording instruments make their records upon a smoked chart which has to be treated subsequently with a fixative supplied with the instrument in case it is desired to preserve the record. The Bristol instruments are regularly made with a clock supplied with a changing lever so that the disc can be made to rotate either in one hour or twenty-four hours. Both the Bristol Company and the Esterline Company have recording instruments which give an ink record on a paper strip. In either type of instrument center scale zeros should be called for so that variations between positive and negative values will be recorded on the chart.

37. Normal Electrode. The Haber normal electrode also called non-polarizable electrode consists of a rod of zinc which is enveloped in a wet paste of zinc sulphate contained in a glass tube which has had cemented to it at the bottom a porous clay cell. The other end of the tube is closed with a stopper from which the zinc rod is supported an insulated wire is led from the end of the zinc rod through this stopper to the upper end of a wooden rod which also enters the stopper and serves for the purpose of handling the electrode. A capillary tube is also run through the stopper in order to have the interior of the tube at normal atmospheric pressure. The zinc sulphate paste is made by adding saturated zinc sulphate solution to fine zinc sulphate crystals until the mixture has attained a semi-fluid condition. A sketch showing details of construction for this device is shown on the opposite page. (See Fig. 2.)

38. Earth Ammeter. The Haber earth ammeter consists of two thin copper sheets laid one upon the other with a thin sheet of mica or other non-absorbent insulating material between them. These two plates are gripped in a hard rubber rim which forms part of a square wooden frame. A paste made by mixing powdered copper sulphate crystals with a 20% aqueous solution of sulphuric acid is spread over the exterior surfaces of each of the two sheets of copper, the paste being enclosed on each exterior surface by a covering of parchment paper or some similar tough permeable membrane. Insulated wire leads of suitable length are run from each plate through the frame to connect with the measuring instrument. The opening in the frame may conveniently be square. Four inches is a convenient dimension for the sides of this square opening as this will yield an area of one-ninth of a square foot which is approximately equivalent to a square decimeter. The detailed construction of the instrument is shown in an attached sketch. (See Fig. 3.) When using the instrument, the spaces between the parchment paper and the outer edges of the wooden frame are first filled with

SECTION OF
NON-POLARIZABLE ELECTRODE



CROSS SECTION
Figure 2

SECTION OF EARTH AMMETER

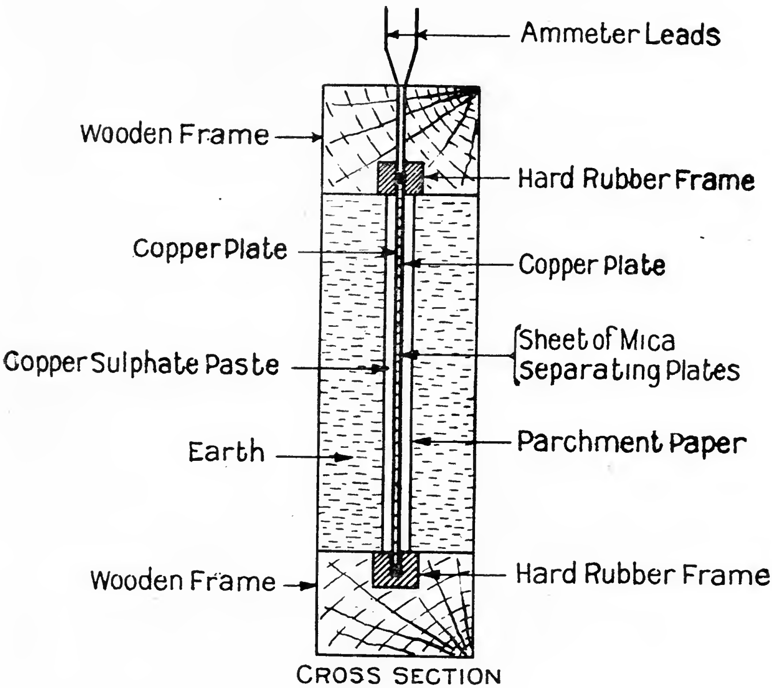


Figure 3

closely packed soil taken from the spot where it is intended to make the measurement and the frame is then placed in a position perpendicular to the flow of current which it is desired to measure and completely buried in earth removed in the course of making the excavation to reach the structure whose condition is to be determined. A suitable low resistance milliammeter can then be connected to the two terminal wires and observations of the current flowing made.

39. Testing Electrodes. The details of metal tipped testing electrodes for use in readings of potential to earth are given in an attached sketch. (See Fig. 4.) Two of these testing rods may be conveniently carried at all times; one of the two should have as its testing tip a piece of the same metal as that contained in the structure whose potential to earth is to be tested, the other should be provided with a steel tip so that contact may be maintained from a distance with any pipe or cable which is below the surface of the ground. The metal on the tips of these rods should always be kept clean and bright and care should also be taken to remove rust and other products of corrosion from the points on the surface of the structure to be tested against which the steel tip presses so that a clean, bright surface will be available for the contact.

C: RECORDS AND REPORTS.

40. General. Much detailed information is necessarily gathered in the course of an electrolysis survey. It is desirable to prepare in advance of the work for the convenient recording of these data upon suitably arranged testing sheets, which either have upon one line or upon one sheet, as may be necessary, all of the data collected at any stated testing point during a single period of observation. Several typical data sheets prepared for recording observations made upon piping and cable systems are attached hereto as suggestive of possible arrangements for report sheets. The data thus collected can usually be best aranged for study if they are transferred to a map showing the system or systems included in the tests, and indicated thereon either in numerical form or through some graphical representation. It is desirable to indicate positive and negative relations by making records on the maps in different colors.

Apart from the data obtained through observations in the

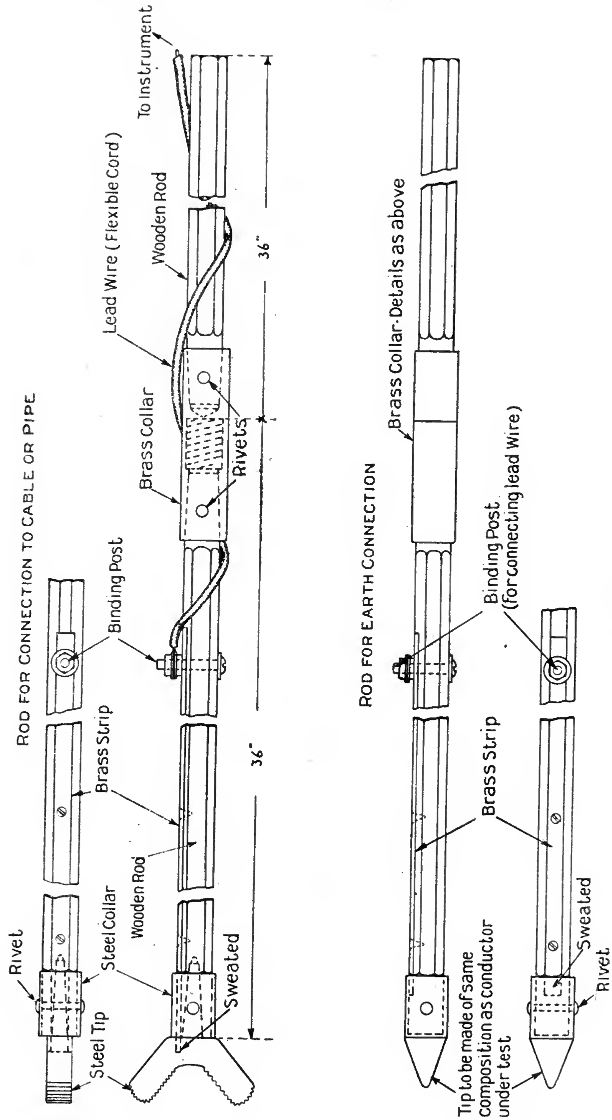

ROD FOR CONNECTION TO CABLE OR PIPE
To Instrument
Lead Wire (Flexible Cord)
Wooden Rod
Brass Collar
Rivets
36"
Binding Post
Brass Strip
Wooden Rod
36"
Rivet
Steel Collar
Steel Tip
Sweated
ROD FOR EARTH CONNECTION
Brass Collar-Details as above
Binding Post
(for connecting lead Wire)
Brass Strip
Sweated
Rivet
Tip to be made of same
composition as conductor
under test

Figure 4

work of the electrolysis survey it will be seen that the records obtained relating to the systems under observation should include the following:

41. Electric Railways.

1. Maps showing locations of sources of power supply, tracks, and negative feeders and other connections between bus-bar and track. Also locations of positive feeding connections to trolley and of all section insulators in trolley.

2. Information as to size of rails, methods of bonding and standards of bond maintenance.

3. Information as to any direct ground connections applied to the railway return system, and any special track features which may affect the flow of stray currents.

42. Piping Systems.

1. Maps showing all main piping lines and branches (except building connections) and sources of water, gas, etc., from which the piping systems are supplied.

2. Information as to sizes of pipes and metals of which they are composed, and details of the standard methods of joining main and branch line pipe sections.

3. Information as to method of joining building connections to main supply pipes including metals used for the building connection pipes and the depth to which such connections are buried.

4. Location and description of any protective devices such as insulating joints or drainage connections which may have been made a part of the piping system.

5. Information as to methods of attachment and construction employed in carrying pipes over highway or railway bridges or under water courses, swamps, etc.

43. Cable Systems.

1. Maps showing locations of all subway and conduit routes and giving number and sizes of cables in place therein or the total cross-section of lead sheaths expressed in equivalent copper, also locations of power stations, sub-stations or other centers from which cables radiate.

2. Locations, route and sizes of all drainage connections attached to cable systems, also locations of all insulating joints in cable systems, of any jumpers which may be run to establish a metallic circuit across an insulated gap in the cable system and of any conductors run to reinforce the carrying capacity of the cable system for stray currents.

3. Information as to methods of attachment and construction employed in carrying cables over highway or railway bridges or under water courses, swamps, etc.

44. Bridges and Buildings.

1. Locations of structures with respect to electric railways.

2. Information as to methods of construction employed in carrying electric railway, pipes and cables across bridges and particularly as to whether any of these other structural systems make electrical contact with the metal structure of the bridge.

45. General Conditions.

1. Maps showing locations of water courses, swamps and other features tending to produce locally earth of high unit conductivity.

2. Records of electrical resistance of soil samples representative of the area.

3. Records of experience obtained in the use of different metals for pipes, etc., in the soils of the area.

It is desirable that in the preparation of records and of reports, consideration be given to the necessity of their perpetuation. All records which will be of permanent value in connection with the continued study of electrolysis conditions within the area which will be necessary in order to make sure that injurious changes in conditions do not occur, should be prepared in a permanent form capable of withstanding considerable handling.

III. AMERICAN PRACTICE.

There is no standard practice in the treatment of electrolysis problems in America. In many localities the existence of such a problem is scarcely recognized; in others the problem has been given much study, and mitigating systems widely varying in character have been installed.

Much of the information made available to the committee is contained in confidential reports to which it is not possible to make reference, because electrolysis is the subject of controversy between conflicting interests. Unfortunately, also it is impossible in some cases even to refer to places where particular expedients have been employed, or to state either the extent or the results of such use. It has, therefore, been necessary in most instances to make statements of what is the practice, without citing the authority or naming the places where such practice may be found. In compiling this report, therefore, the committee has been influenced most largely by those instances of practice within its knowledge where the greatest amount of study has been given to the subject, and where the results obtained seem best to justify its use. The committee has embodied in this report only matters of fact for which it has authority.

A. MEASURES APPLIED TO RAILWAYS.

46. Insulation. Under this sub-heading have been considered three general measures, namely: *a. Complete Insulation*, which does not involve the use of the running rails as a portion of the electric circuit, *b. Substantial Insulation*, which does involve the use of the running rails as a portion of the circuit, but, due to the type of construction employed, to a very large extent prevents stray currents, and *c. Partial Insulation*, which comprises using such means as are available to insulate the running rails of ordinary street railways in so far as practicable.

(a) **Complete Insulation.** Instead of using the running tracks as part of the return circuit, a separate insulated return conductor is employed for this purpose. In this case the entire electric circuit of the railway system is insulated from ground, and, there being no voltage drop in contact with earth, stray currents are entirely prevented. Complete insulation of the railway circuit is accomplished in the double underground conduit trolley system, by employing insulated positive and negative conductors in underground conduits. This system is in use on the surface lines on Manhattan Island and in portions of Washington, D. C. This is also accomplished in the double overhead trolley system by employing separate positive and negative overhead trolley wires insulated from ground; many years ago examples of this system were installed in Washington, D. C., and Cincinnati, Ohio. The practice while effective in this respect and in use for a long term of years has not spread to other cities possibly because of the unsightly appearance of the overhead structures due to the multiplicity of wires and because of the increase in operating difficulty and expense which it entailed.

(b) **Substantial Insulation.** Interurban and electrified steam roads generally require the rails to be supported on wooden ties set in well drained broken stone or gravel ballast. The insulation afforded by such construction practically removes danger from electrolysis. Leakage is in some instances found to be as low as .00016 ampere per rail per tie under dry weather conditions, increasing to .0055 ampere when wet with 10 volts between the rail and ground. On steel structures where the ties are only partially in contact with ground and the ties cannot become waterlogged, this leakage is even less. The substantial insulation of a ballasted roadbed has, in some installations, been rendered ineffective by bare negative cables in damp earth or by metallic connections between the tracks and steel supporting construction. Conditions are found to be very favorable for rail insulation where the tracks are in subways or under cover protected from the weather, permitting the ballast and ties to become permanently dry.

(c) **Partial Insulation.** The escape of current from tracks largely buried is decreased by high contact resistances between the tracks and the surrounding medium. The total resistance to flow of escaping current is found to vary with the earth resistance and the contact resistance between earth and rail. Since the earth resistance is usually low, the contact resistance is generally found to be the controlling factor in the leakage path; hence, partial insulation is found effective in reducing leakage with the low voltages commonly encountered. On a grounded trolley system in city streets it has been found beneficial to have the rails as nearly enclosed with insulating material as possible.

47. Reduction of Track Voltage Drop.

(a) **Bonding.** The best types of solid rail joints in actual use give the same electrical conductivity at the joint as in any other part of the rail length. The standard of good practice in some electrified steam roads is that, the resistance through the rail joint shall be equivalent to that of a 20-inch length of the rail adjacent, and should the resistance exceed 42 inches, that the bond should be remade. With respect to the practice of bonding in street railway systems, it may be said that there is no standard equivalent length of rail to cover all conditions, but each railway company establishes its own standard, depending on local conditions. The equivalent resistance of the rail joint in terms of length of rail will depend on the length and size of the bond, the terminal contact resistance and the conductivity of the rail. In large cities bonding to an equivalent resistance of from three to six feet of rail is common practice. In suburban districts higher bond resistances are often used. The equivalent resistance of rail joint which is adopted by different railroads necessarily varies widely with the condition of load and class of bond employed. The class of bond chosen is in many cases determined by mechanical conditions, such as the foundation upon which the track is laid.

Bonds are generally classified according to the method of fastening them to the rail. *Soldered bonds* are soldered to the head, base or web of the rail. *Pin expanded bonds* have holes drilled in their terminals, through which a steel pin is driven to expand the terminal into a hole drilled in the rail. After expansion a steel cylindrical plug is driven in the expanded hole to prevent contraction. *Brazed or welded bonds* are attached to the rail by heat generated electrically or by an oxy-acetylene flame applied to the terminal of the bond. *Compressed terminal bonds* and *compressed multiple terminal bonds* have their terminals formed into a solid cylindrical stud, or studs, and are compressed in the rail holes with screw or hydraulic compressors or by hammer blows, which expand the studs in threaded or beaded holes of the rail. A special type of this bond has large contact surfaces about the terminal, so that the bonds can be soldered and compressed to the rail.

The carrying capacity of bonds has sometimes been found insufficient to keep their temperature within safe limits under conditions of maximum load where bonds involving soldered joints are used. The resistance of a rail joint is found to be affected largely by the contact resistance between the bond terminals and the rail. Good contact and large surface of contact at the bond terminals are found necessary to low joint resistance. Replacement of bonds is generally made necessary by depreciation at the contacts, the breaking of strands by vibration or by mechanical injury.

There are now in general use several different types of rail joints which render additional bonding unnecessary. Among these types of rail joints are the following: *Cast Welded*: The rails are connected together by pouring molten iron into a mold that surrounds the joint, and when the metal cools the joint is rigid and of low electrical resistance. Thermit welding is another example of this method, the iron being liberated at a white heat from a mixture of iron oxide and aluminum which is ignited in a crucible. *Electrically Welded*: Iron splice plates are electrically welded to the rail. *Nichols Zinc Joints*: This joint is made by pouring molten zinc between the fish plates and the rail ends. The zinc is poured in after the fish plates are bolted on, and the expansion of the zinc in solidifying is relied upon to make a contact between the fish plates and rail ends which is reported to be permanent. *Romapac Continuous Rail*: The rail consists of two pieces which are so laid that the rail head joint and the rail base joint are staggered, then the rail head is rolled or crimped on to the rail base thus forming a continuous electrical path.

(**b**) **Cross-bonds** are electrical conductors for equalizing the current flow in the rails. When the roadbed is dry they are usually installed bare in the ground. Insulated cable is, however, sometimes used, and the insulation is protected by a heavy braid or circular loom tubing.

The important objects of cross-bonding are to equalize the current flow between rails and to insure continuity of the return circuit in case of a broken rail or bond in any one rail. It is usual practice on suburban railways to place cross-bonds at intervals of 1,000 to 2,000 feet and at shorter spacing, sometimes as low as 300 feet on street railways. Cross-bonding between parallel tracks is in some cases installed with the same frequency as between the rails of the single track; in other cases at less frequent intervals.

In determining the location of cross-bonds in connection with alternating current single track signal circuits, a departure from ideal spacing becomes necessary, owing to the fact that cross-bonds are permissible only at the reactance bonds. The signal reactance bonds are located between the signal block sections, and these sections are more or less fixed for train operating conditions. The general method used under these conditions is to cross-bond at all signal reactance bonds and install additional cross-bonds with reactance bonds at intermediate locations to obtain the most satisfactory resistance conditions in the sections fixed by the signal system.

The common practice of electrified steam railroads is to use cross-bonds with a conductance equal to one track rail, or about 1,000,000 circular mils. Street and interurban railways employ copper having a cross-section of from 200,000 to 500,000 circular mils.

Some companies provide jumpers at switches, frogs and at other special track work, to insure that the electrical continuity of the bonded rail will be maintained. This is usually accomplished by jumpers extending around the special work, except where broken rail signal protection is required, and in such cases the frogs are bonded in the return current system. In recent practice these jumpers are made of insulated copper cables, except in dry locations, as, for instance, in permanently dry rock ballast, or on elevated structures with wooden ties and no ballast, the cables being kept clear of the steel structure. The electrical leakage from a bare negative jumper in damp earth has been known to offset the effect of many miles of most careful track insulation. Under such conditions the bond is gradually destroyed by electrolysis.

(c) **Conductivity and Composition of Rails.** The conductivity of the track rails used by several interurban and electrified steam railroads has been found to be equivalent to about 1/12 that of copper, and this figure generally holds approximately true for girder types of rails, except when alloy steel is used, in which case higher resistances are found. The track rails are specified for their mechanical qualities, and, where these interfere with the electrical requirements, it is customary to give the mechanical qualities preference. The composition of rails for heavy service used by one of the large electrified steam railroads, in percentages, is as follows:

Carbon	0.62 to 0.75
Manganese	0.70 to 1.00
Silicon	0.10 to 0.20
Phosphorus	not to exceed 0.04

The American Electric Railway Engineering Association has adopted the following standard composition for heavy service rails:

	Class A Rails	Class B Rails
Carbon	0.60 to 0.75	0.70 to 0.85
Manganese	0.60 to 0.90	0.60 to 0.90
Silicon	Not more than 0.20	Not more than 0.20
Phosphorus	Not more than 0.04	Not more than 0.04

d. Reinforcement of Rail Conductivity. Early track construction practice in this country often included bare wire laid between the rails and connected to each bond. Sometimes one such wire was used for each rail; sometimes one for each track, and sometimes one served for a double track. The wires varied from No. 4 to No. 1, and were either of copper or galvanized iron. Their conductivity was small and they were subject to electrolytic injury and frequent breakage. This construction has practically gone out of use. It is, however, common to find the rails supplemented in the vicinity of supply stations by large conductors connected in parallel to the rails. This is not infrequently done by the use of bare copper wire or cable buried between rails, and hence in full contact with the earth. Old rails, bolted and bonded together and buried beneath or beside the track, have also been used in some cases.

Buried bare conductors, however, increase the contact area between the return circuit and the earth, and the tendency to augment stray currents thus caused off sets, to a greater or lesser extent, the benefits attained by the reduction of drop. The benefits to be derived, therefore, from an electrolysis standpoint, may, if use is made of bare conductors buried in the earth, be open to question. The direct benefits that accrue from the practice of reinforcing the conductivity of the rail, listed in what may be considered their order of importance, are: (1) Reduction of energy losses; (2) The maintenance of a higher average voltage at the cars, especially at times of peak load, thus resulting in improved car service and car lighting; and (3) The reduction in potential drop in the rails, thus reducing stray currents and, in turn, therefore, lessening the damage to the extent that these stray currents are reduced, qualified, however, in accordance with the statement previously made if buried bare conductors are used.

Where conductors paralleling the rails are installed as an electrolysis mitigation measure, they are usually insulated from earth by carrying them overhead or in underground conduit. The practice varies as to the method of connecting such conductors to the rail; they are sometimes connected at the ends only but more generally at intermediate points also. Where this arrangement is used the track rails are connected to the negative bus at the nearest convenient point.

Conductors are here regarded as in parallel with the rails when one end is connected to the track and the other to a station bus-bar which is connected directly to the rail by a conductor of negligible resistance. The use of such conductors should not be confused with the "Insulated Track Feeder System," which has for its prime object the mitigation of electrolysis. This is treated under a subsequent heading.

(e.) **Use of Additional Power Supply Stations and Distribution of Load.** The growth of electric railway systems in large cities has often led to the installation of additional power stations or substations for the more economical and satisfactory operation of the railroad. This has also reduced the track voltage drop and subdivided the areas over which leakage from rail to earth occurs and thus has had the effect of reducing the stray currents.

The effect of providing additional centers of power supply can best be illustrated by the curves on Figure 5, which, while deduced from theory, illustrate in a simple case effects such as have been observed in practice.

The curve *SAO* of Figure 5 represents the track voltage

Reduction of Track Voltage Drop by Additional Power Supply Stations

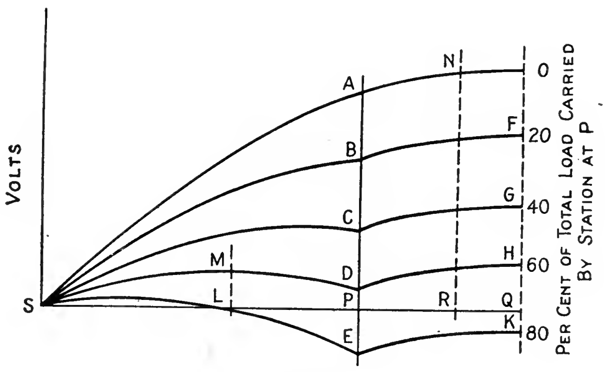


Figure 5

drop on a portion of an electric railway system having a uniformly distributed load. This curve is a parabola with a vertical axis and with the apex at *O*—that is, at the end of the line.

The curve *SBF* illustrates the condition of a substation located at *P* (33 per cent of the distance from *Q* to *S*) carrying 20 per cent of the total load. In this curve the portion *BF* is identical with *AO*. As the load is uniformly distributed, 33 per cent of the load is on the portion of the line shown by *PQ*, and of this 33 per cent, 20 per cent is carried by the substation *P*. The remainder, or 13 per cent, is carried by the station *S*. The point *B* on the curve *SBF*, therefore, corresponds to the point *N* on the curve *SAO*, the distance *QR* being 13 per cent of *QS*.

In the same manner the curves *SCG*, *SDH* and *SEK* are drawn showing the conditions when the station *P* carries 40 per cent, 60 per cent and 80 per cent, respectively, of the total load. The summit of the curve *SMD*, in which the station *P* carries 60 per cent of the load, is located so that *PL* equals 60 per cent minus 33 per cent, or 27 per cent of the total length *SQ* to the left of *P*. The distance *QL* is, therefore, 60 per cent of the total length *QS*.

In general, the conditions are more complicated than those here assumed, and will ordinarily prevent an accurate determination of the relative location of the negative busses of the two stations. It is possible, however, to make tests which will verify each of the points which have been used in preparing the curves, although it may not be possible to verify all of them at any one test or in one location.

48. Three-wire Systems. As far back as 1894, and possibly earlier, consideration was given to a three-wire system of operation for electric street railways, wherein the tracks acted as the neutral circuit. The reason for considering such a system was to reduce stray currents through the earth. Installations of this sort were tried out in Pittsburgh, Pa., Lowell, Mass., Portland, Ore., and Seattle, Wash., in the earlier days; somewhat later an experimental installation was made in Cambridge, Mass. In the *Transactions* of the American Institute of Electrical Engineers for 1907, Vol. XXVI, No. 1, pages 268 to 280, Messrs. Paul Winsor and J. W. Corning report the results of an investigation to determine the feasibility of using the three wire system for the purpose of reducing stray currents through the earth. This investigation showed that the three-wire system of operation materially reduced the track voltage drop, and therefore reduced the amount of stray current in the earth and in underground metallic structures. The figures and curves shown by Mr. Corning indicate that there is a reduction in current flowing on pipe lines tested by him of the order of nearly 90 per cent.

Until very recently it was thought that three-wire systems contained certain serious inherent disadvantages. It was felt that the complications in machinery, difficulties in successfully insulating trolleys of different polarities, difficulties in equalizing the load between different sections, and, further, the necessity for the installation of larger generating units to compensate for the difficulties in balancing than were required with the single-trolley grounded system, were so great as to preclude the consideration of the three-wire system for electrolysis mitigating purposes. Recently, however, interest in this system has been renewed, and at least some of the difficulties successfully overcome, with the result that at the present time there are in operation or being installed two sectionalized three-wire systems—one in operation in the Hollywood district of Los Angeles, Cal., and the other in process of installation in West Springfield, Mass. It is known that the three-wire system has been in operation for some twelve years in Nürnberg, Germany, and for a considerable length of time in Brisbane, Australia.

The three-wire system may take two different forms, which, though the same in principle, differ decidedly as to the arrangement of the feeders. In one form, known as the *Parallel Three-wire System*, one trolley of a double track road is negative and the other positive, the tracks being neutral. In the other form, known as the *Sectionalized Three-wire System*, the feeding district is divided into sections and alternate sections are supplied by feeders running directly from the positive bus, while the remaining sections are supplied by feeders from the negative bus. For a more detailed description of these two forms of three-wire systems reference is made to the Bureau of Standards' Technologic Paper No. 52.

49. Reversed Polarity of Trolley System. With the ordinary construction of electric railways using the running tracks as a part of the electric circuit, the overhead trolley wire or third rail is made the positive conductor, and the running tracks the negative or return conductor, only one exception to this rule being known to the Committee. With the usual arrangement stray currents escape from the running rails into ground and flow to underground structures at points distant from the power station, and such escape of stray currents from the rails generally takes place from a large area of outlying lines. The current then returns to the tracks from ground and from underground structures in the neighborhood of the power station. For this reason the most acute danger from electrolysis is usually produced on underground structures in the neighborhood of the power station.

To reverse this arrangement of polarity and make the rails the positive conductor, causes current to leave the structures over widely scattered areas, so that the current density leaving the underground structures will be so small as to prevent acute danger from electrolysis. This arrangement is being used in New Haven, Conn. at the present time. It is found, in this instance, that all potentials and currents which formerly existed when the rails were the negative conductor have now reversed in direction, but have the same magnitude. It is also found that current leaves underground structures over a widely scattered outlying area. This arrangement has not been in operation a sufficiently long time to determine whether or not the danger from electrolysis at any one outlying point will become acute. The reversal of polarity renders extremely difficult the effective drainage of underground structures, because there is no definite point of minimum potential to which to drain.

50. Booster System. Negative boosters have, in the past, been employed in connection with drainage systems, and are in use in connection with the insulated track feeder system abroad, but not in this country, so far as known. The use of negative boosters is simply a means of caring for voltage drop other than by the use of copper. Boosters have proved economical under certain conditions, and uneconomical under others. In general it is simply a question of the fixed charges on copper as against the fixed charges and operating cost of machines. In one instance where a booster was employed in connection with a drainage system it was discontinued, not because the addition of a booster to a drainage system was unsatisfactory, but because the drainage system itself did not adequately care for the trouble. Various special arrangements involving the use of boosters in electrolysis mitigation have been proposed, but in so far as is known they have never been placed in successful operation.

51. Interconnection of Railway Return Circuits. Wherever two or more electric railway tracks come close together, whether they belong to the same railway system or to different railway systems, large differences of potential between them, with resultant high potential gradients through ground, are often found to occur unless the tracks are electrically connected. Interconnection of tracks has been found to be of particular advantage where two or more lines of electric railway, operating in one locality and belonging to the same or to different systems, are supplied from two or more power stations located in different parts of the city. By interconnecting the tracks of such lines in the neighborhood of the power stations, and also at several intermediate points, an interchange of current has been brought about, whereby the drop formerly existing in one track has been balanced by the drop in the opposite direction in the other track, the rail drop in each track greatly reduced, and all high potential gradients between the tracks eliminated. This reduction in rail drop resulted also in a corresponding reduction of losses.

52. Use of Alternating Currents. When the first alternating current railways were proposed, the question of possible electrolytic effects received special investigation. Considerable work was done upon a laboratory scale, in which it was established that alternating currents could produce corrosion on electrodes of the metals commonly used underground, such as lead and iron, but that the effects were very much less in magnitude than those produced by equivalent quantities of direct current, usually less than one per cent and in most cases negligible.

It has not as yet been possible to determine whether these effects, demonstrated in an experimental manner, are being reproduced in the case of actual installations. In the case of practically all actual exposures which have occurred up to the present time it has been impossible to dissociate effects which might be due to an alternating current exposure from the effects which are due to a simultaneous exposure to stray currents from direct current railways. Whether alternating current corrosion is proceeding at the relatively slow rate indicated by the experimental investigations and will at some time produce damage to subsurface structures, cannot now be determined. Special measures for the reduction of leakage of current to earth are being tried out in one alternating current railway, but neither the construction nor the results have yet been made public. (See Bureau of Standards Technologic Paper No. 72.)

53. Insulated Track Feeder System. The insulated track feeder system or the insulated return feeder system is employed in a number of American cities at the present time, and plans are being made looking to its installation in a number of other cities.

The arrangement of feeders described under this title is not generally understood, and as it is commonly confused with the reinforcement of track conductivity, the following explanation is therefore made.

Stray current which is the cause of electrolytic corrosion is traceable directly to voltage drop in the rails. With a given resistance between rails and earth any means which will most effectively reduce this voltage drop is, therefore, the means which will most effectively reduce electrolytic corrosion. The reinforcement of the conductivity of the rails by paralleling them with other conductors operates definitely in this direction, provided the paralleling conductors are not themselves in contact with the earth. When, however, it is desired to reduce the voltage drop to such a point as will insure reasonable immunity from electrolytic troubles, the employment of copper in parallel with the rails generally proves prohibitively expensive. For example, an average grade of rail has a resistance $12\frac{1}{2}$ times that of copper of the same cross-section. Its conductivity is therefore approximately the equivalent of 10,000 c. m. of copper per pound per yard. Such a rail weighing 100 pounds per yard would be approximately equivalent to a 1,000,000 c. m. cable. To reduce the track voltage drop to one-half its former value, where such a rail is employed, would require a 1,000,000 c. m. cable laid parallel to each rail of the track for its entire length. This large investment in copper would reduce the losses of track transmission by but one-half, and would reduce the stray current by one-half. If bare copper in contact with the earth were used the stray current would be reduced by somewhat less than one-half. Thus, the practice to install return copper to reduce track drop with a grounded bus-bar is either prohibitively expensive or ineffective. It was because of these recognized difficulties that the *Insulated Track Feeder System* was introduced.

The insulated track feeder system employed in the American cities above referred to has the following distinguishing characteristics:

(a) The negative bus is insulated—that is, not connected to earth nor directly to the rails at or near the power or sub-station, except that, in some instances, it is connected to the rails through resistances sufficient in magnitude to insure that this point is at approximately the same potential as other track feeder points.

(b) The current is returned to the negative bus by insulated feeders leading from selected points on the track network.

(c) These feeders are connected to the track at their extremities only, or, if connected at intermediate points, are connected through resistances of such magnitude as to keep all connected points at approximately the same potential with respect to the bus.

The *Insulated Track Feeder System* is thus an arrangement having for its prime object the reduction of stray current through the earth. The insulated feeders are installed either overhead or in underground ducts, and extend from the negative bus to such points on the track network as have been determined, by either observation or computation, to be those from which the removal of current will prevent excessive track voltage drop. The negative bus is connected to the rails at the power house only through a resistance sufficient in magnitude to insure that this point is at approximately the same potential as other feeder connection points. When all feeder connection points are at the same potential the maximum effectiveness of the system as a means of reducing stray currents is found. The attainment of this condition requires track bonding of a reasonably high order of uniformity.

In most cases feeder connection points are not brought to the same potential, but a certain drop is allowed in the direction of the power station.

The insulated track feeder system is the equivalent of having the negative bus-bar of the power supply station divided into branches corresponding in number to the number of track feeder points, and distributed geographically over a considerable portion of the track network. This reduces both maximum and average current in the rails and also reverses the direction of the current in the rails on one side of each feeder point. These changes in the rail current directly reduce track voltage drop. The area from which current leaks to earth and to underground structures, and also the area from which current returns from underground structures and earth to the rails are subdivided. The combined effect of these factors is a substantial improvement in electrolysis conditions of underground structures. (See G. I. Rhodes, Trans. A. I. E. E., 1907.)

The efficacy of this system in reducing stray current is practically independent of the weight of copper in the individual feeders—that is to say, the voltage drop in the feeders may be either large or small, without material effect upon the stray currents.

As was pointed out under a prior sub-heading, negative boosters may be used with this system. The principles underlying the insulated track feeder system are the same, whether or not negative boosters are used.

B. MEASURES APPLIED TO AFFECTED STRUCTURES.

54. Insulating Joints in Large and Small Iron Pipes and in Lead-sheathed Cables. In a number of installations flow of stray current on metallic pipe lines has been prevented by the use of a sufficient number of insulating joints. It is found that where a pipe line is laid with every joint an insulating joint, the line has such a high electrical resistance that no measurable current flows on the line, although considerable potential gradient exists in earth parallel to the pipe line. In some installations it has been found sufficient to use comparatively few insulating joints to break up the electrical continuity of a pipe line and protect the line from electrolysis, but in these cases it was necessary to make adequate tests to assure that sufficient current did not shunt through earth around the joint to damage the pipe on the positive side of the joint. In these installations it has been found necessary to install such insulating joints, not only in the positive areas, but also in the negative areas in all places where considerable potential gradient in earth parallel to the pipe existed. It is found, in fact, that the frequency with which insulating joints must be installed in a pipe line in order to assure reasonable protection from electrolysis, depends upon the potential gradient through the earth and upon the electrical resistivity of the earth in the neighborhood of the pipe line.

Tests on joints buried in earth have shown that the resistance of a short insulating joint is practically the same as that of a long joint, but that a long insulating joint gives a more even distribution of leakage current than a short joint, and that, therefore, a long insulating joint is to be preferred where there is considerable potential difference across the joint or where the resistivity of the surrounding soil is very low. It has also been found that the effect of a long joint can be secured from a short insulating joint by surrounding the joint and the pipe for some distance on each side of the joint with a heavy layer of insulating material. In a number of installations of such insulating joints in important pipe lines, each joint and the pipe for a distance of from 5 to 25 feet on each side of the joint have been surrounded by a wooden box leaving a space of from 1 to 2 inches between the outside of the pipe and the inside of the box, and the space then filled with pitch, parolite, or similar material. In this way an insulating joint having an effective length of from 10 to 50 feet was secured. (See also Bureau of Standards Technologic Paper No. 52).

In a large number of cases small service pipes have been damaged by electrolysis from stray current leaving the service pipes for earth, which current was found to flow to the service pipes either from the main or from house piping. In the latter case the current was found to reach the house piping by way of a service pipe from another piping system. In some cases of this kind such current flow to service pipes has been greatly reduced or prevented and the service pipe thereby protected from electrolysis, by placing an insulating joint in the service pipe at the main or in the building, as the case may be.

In some cases it was however found necessary to install an insulating joint in the service at the main and a second joint in the building, the necessary locations of the joints being determined from the results of electrical measurements. This method of protecting pipes has been applied to isolated cases which were specially studied, but has not been generally applied to a large complicated city system of mains and services.

For wrought-iron or steel pipes of small and moderate size, various commercial insulating joints have been largely used. For large sizes of pipe a flanged type of insulating joint has been commonly used. This insulating joint has been made up by placing a disc of insulating material between the surfaces of the flanges, by placing insulating tubes over the bolts, and by placing insulating washers under the bolt heads and nuts. Red fibre has been most commonly used for the insulating material, except that for water pipes in some cases soft sheet rubber has been used for the packing between the flanges. Where such flanged insulating joints have been used in cast-iron mains the flanges have generally been cast as part of the pipe.

For water mains various forms of insulating joints employing white pine wood for the insulating material have also been used to a considerable extent. For cast-iron water mains with bell and spigot joints, these joints have in some installations been rendered insulating by placing a short wooden ring between the inside of the bell and the end of the spigot to prevent metallic contact between the pipe lengths, and then calking the joint with wooden staves of clear white pine shaped to fit the curvature of the pipe. In these cases the spigot end of the pipe was either cast without a bead or the bead was removed. The leaks that developed in the joint were stopped with white pine wedges. These simple joints have been found satisfactory for pressure up to about 75 pounds per square inch (5.27 kg. per sq. cm.) Where with higher pressures leakage developed through the pores of the wood, this was overcome by dipping the inner ends of the staves in red lead. The staves have also been reinforced in some cases by an iron band clamped around the spigot end of the pipe.

It is found that cement joints in cast iron pipes as ordinarily made have a very high resistance between adjoining lengths of pipe and that such joints may properly be classed as insulating joints. When pipe lines are laid with every joint, or even every other joint made of cement, the resistance of the pipe line becomes so great that the current flowing on the pipes will be greatly reduced. In practice, however, for mechanical reasons it has been found that cement or other insulating joints cannot be used under all conditions or for all sizes of pipe. In such cases, the entire drop of potential of the pipe line is distributed more or less uniformly over all of the cement joints and the drop in potential around any one joint is too small to cause any injury through leakage of current around individual joints unless the soil is of great conductivity.

This, however, will not prevent electrolytic corrosion in localities where current can reach the pipe by way of laterals, or when it is closely adjacent to other conducting structures which nullify the effect of the joints, or when there is leakage from another transverse pipe.

Insulating joints in lead sheaths of underground cables are in use to some extent, but they are not found to afford an effective primary means of preventing electrolysis. In some installations such insulating joints have been used in positive areas for the purpose of breaking up the electrical continuity of the lead cable sheathing and stopping rapid localized destruction from electrolysis, but such joints have not generally been found to afford permanent and complete protection. In certain special cases in practice insulating joints have been used in the lead sheaths of certain cables for the purpose of preventing current from reaching the remainder of a cable system. Common examples of this are found where laterals or services from a cable system pick up considerable current from an iron conduit or from pipes with which the cable or iron conduit may be in accidental metallic contact, which current is then delivered to the cable system. Such current flow to the cable system has frequently been effectively stopped by introducing an insulating joint in the lead sheath of the lateral or service where it leaves the iron conduit and before it is connected to the main cable system.

Particular points on main cable runs have also been found where considerable current was picked up. Such cases have frequently arisen where a cable crosses a bridge in an iron conduit, and where the conduit is in metallic contact through the structure of the bridge with trolley tracks on the bridge, whereby large currents were found to flow from the tracks through the bridge structure and iron conduit to the cable system. In such cases insulating joints have been installed on each side of such sections or crossings so as to interrupt the metallic continuity of the main cable sheath and prevent current from the bridge reaching the cable system. Where, after this was done, considerable potential differences were found to exist across the outer ends of the cable sheaths, these were equalized by connecting the cable sheaths at the two ends together by an insulated wire.

A simple and cheap form of insulating joint for lead cable sheaths which has been very generally used consists in cutting out a narrow strip of lead and covering the break with a suitable insulating and waterproof material so as to effectively prevent entrance of moisture.

This method of protecting underground structures has not been widely used as a primary means of electrolysis protection, partly because of the great expense involved. Further, insulating joints unless used with caution may introduce serious trouble at many points. This method has proved useful especially in certain new installations, but to protect existing installations by this means would involve prohibitive cost. It is usually regarded as a suitable auxiliary measure to be used in certain cases which cannot economically be taken care of by other means.

55. Insulating Pipes, Cables and Structural Steel from Earth. Many attempts have been made in practice to protect underground pipes from electrolysis by insulating the pipes from earth by paints, dips or insulating coverings. It has been found, however, that no dip or paint will permanently protect a pipe from electrolysis in wet soil. The first difficulty that is met is to apply the paint so as to form an absolutely perfect coating, and then to prevent mechanical damage to the coating. Where a coated pipe is in a positive area it has been found that aggravated trouble from rapid destruction of the pipe has resulted at spots in the pipe where there are imperfections in the coating. It has further been found that even where paints or dips are apparently intact, electrolytic action has taken place causing severe pitting under apparently good coatings. It has been found that in most cases the coatings applied have either been completely destroyed by the effects of the wet soil and electric currents, or defects in the coating have developed, causing concentrated corrosion at such defective spots. It has, in fact, been found that pipes located in positive areas covered with imperfect insulating coatings are more rapidly destroyed by electrolysis than bare pipes under the same conditions. It has been found that coating pipes in negative areas with insulating coverings accomplishes some good by reducing the amount of stray current which reaches the pipe.

Investigations indicate that the destruction of paints in wet soil where subjected to an electric current is probably due to a trace of moisture finding its way through the coating, giving rise to the flow of a feeble current and resulting in a very slight amount of electrolysis. The gases and other products of electrolysis then form blisters and finally rupture the coating.

Attempts have been made in practice to apply a molten material like pitch or asphaltum to a cold pipe in the field by means of brushes, but it has been found impossible to completely cover the pipe in this way. A type of insulating covering which has been successfully applied in a number of installations, and which appears to afford certain protection, consists of a layer of at least from 1 to 2 inches of a material like pitch or parolite of such a grade that it is not brittle and so will not crack, but yet is hard enough to remain in place. It has been found best to apply such a layer by surrounding the pipe with a wooden box, supporting the pipe upon creosoted blocks of wood or upon blocks of glass, and then filling the space between the box and the pipe with the molten material. The cost of carrying out such an installation is, however, large. The method has been applied in special cases, such as service pipes in very bad localities, and in the case of some very important individual pipe lines of comparatively small size.

Attempts have been made to protect a pipe from electrolysis by imbedding it in cement or concrete, but these attempts have not been successful, even where the cement or concrete was several inches in thickness. The reason for this is that concrete in damp earth acts as an electrolytic conductor, like damp soil, and therefore cannot afford protection from electrolysis.

The following experience and practice is that of a gas company in a large city which uses cast-iron pipes in general in their distributing system with wrought-iron services. They make it a uniform practice to protect all of their service pipes with an insulating coating. As a preliminary the pipes are first cleaned with a wire brush, in order to remove all scale. They are then dipped into a hot coal tar compound, then wrapped for the entire length with a strip of canvas, and then again dipped in the compound. In spite of this protection, however, they have some trouble with their services. The difficulty is due to their inability to get a continuous coating over the entire surface of the pipe. Small pin holes are left in the coating due to minute bubbles of air, or some similar cause, so that if the pipes are positive the flow of current from the pipe through moist earth is confined to these minute pin holes through the insulating compound. The result is that the action of the current forms a small blister of iron rust at the point where the pin hole is located, and after the blister becomes so large as to loosen a piece of the compound, the action takes place at a very rapid rate and soon destroys the pipe. In some locations some of the service pipes have to be renewed within a period of six months on account of the leaks caused by the electrolytic corrosion.

Attempts have been made to insulate lead-sheathed cables from earth, but these attempts have not generally been attended with beneficial results. The experience of the telephone companies, who are the largest users of lead-sheathed cables, has been that it is futile to attempt to insulate lead-sheathed cables from earth. It is, however, the practice of the telephone companies to make every effort to prevent metallic contact between their lead-sheathed cables and other grounded structures throughout the run of the cable, except where it has been determined by a careful survey that a drainage connection to some particular structure is required for the protection of the cable.

The use of insulating ducts has been proposed at various times, but investigations of the telephone companies do not show that their use affords satisfactory insulation of the cable sheaths from earth, with the result that the telephone companies do not place any reliance in any insulating property that any of the duct material may inherently possess. The principal duct material at present used by the telephone companies for main cable subway runs is vitrified clay and creosoted wood. For laterals and short cable runs iron pipe is frequently used.

Laying telephone cables in troughs and surrounding them solidly with asphalt was a method employed in the early days of telephone construction, but this method was abandoned because of its inflexibility and because of the great difficulty of repairing defects or replacing cables. It was further found that this method did not positively insulate the cables everywhere from earth on account of cracks and other discontinuities in the asphalt which were found in practice to develop.

Steel tape armored cables protected with a thoroughly saturated jute covering have been used buried directly in earth. Such covering has been found to be effective for a number of years in protecting the armor against electrolytic corrosion, except at points where the jute has been abraded or cut so as to expose the metal.

Where steel structures extending underground are located so as to be subjected to electrolytic action, the portions below ground have been enclosed with insulating materials. For this purpose any material that excludes water, as for instance paints having an asphalt base, have been successfully used, while many of the ordinary paints have not been found effective. It has also been found that surrounding steel with concrete where this is imbedded in damp earth does not afford absolute protection against electrolysis, although the electrolytic action is most severe at first and becomes less with time, because the formation of chalk in the concrete fills the pores of the concrete and increases its resistance and the iron oxide forming on the surface of the metal also increases the resistance. Special preparations of Portland cement properly applied so as to be watertight have also been found to afford good protection.

56. Shielding, or the Use of an Auxiliary Anode. In some special cases underground structures have been protected from electrolysis by connecting to the structure an auxiliary metallic conductor located so as to cause the current to flow to earth from the auxiliary conductor. This mode of protection is known as shielding. When applying this method it has been found necessary to take care that the auxiliary shielding conductor does not merely increase the electrode areas from which the current leaves, because in this case the current will continue to leave from the structure which is to be protected. This has been found to be the practical result where a shielding conductor of the same or less contact area was placed in earth near the structure to be protected and where the stray current then left from both structures. The shielding conductor must be so placed that current will be prevented from leaving the structure to be protected or so as to cause its magnitude to be greatly reduced. The method has in some installations been applied to a structure which forms the dead end of an underground metallic system and where the structure is highly positive to earth. In cases of this kind it has been found that the current leaves at relatively high density from and near the dead end of the structure, with the result of rapid destruction of the portion near its dead end. In such cases an auxiliary shielding conductor of adequate contact surface extending beyond the dead end and electrically connected to the structure to be protected has been installed in such a manner that the bulk of the current was caused to leave the auxiliary shielding conductor, thus affording a certain degree of protection to the dead end of the structure.

The shielding method has also been effectively applied for the protection of relatively small iron or steel pipes, such as service pipes. In these cases the service pipe has been surrounded by a larger metal pipe electrically connected to the smaller pipe. One application of this method which is in use is that of a service pipe crossing under tracks or crossing other structures to which it is positive and where the pipe comes relatively close to the rails or other structures at the point of crossing. In these cases a larger shielding pipe, usually of heavy cast iron, has been placed around the service pipe and electrically connected to the service pipe and extended sufficiently on each side of the crossing so that the major part of the current was caused to leave the shielding pipe, thereby corroding the shielding pipe while protecting the service pipe.

57. Drainage of Earthed Metallic Structures.

(a) **Lead-sheathed Telephone and Power Cables.** The method of protection against electrolysis used generally by telephone companies for their cable sheaths consists of installing insulated conductors, called drainage wires, between the negative return system of the railway and points on the cable system where the positive potential to earth is highest. The purpose of these drainage wires is to conduct the stray railway current from the cable sheaths to the railway negative return circuit, thereby preventing this current from flowing from the cable sheaths to earth and causing corrosion from electrolysis. In order to afford complete protection it has been found that such drainage wires must have sufficient conductivity and must be so located that the lead sheath of the cable network is everywhere lower in potential than the adjacent earth.

As the potential of the cable sheath is lowered by the connection of the drainage wire from the railway negative return circuit the current flowing on the cable sheath is thereby increased. In order that this current does not become excessive, care is taken to prevent contacts between cable sheaths and other underground structures, through which currents could flow to the cable sheaths.

The drainage method is also employed to a considerable extent for the protection of underground power cables, and the principles involved in its application are the same as for telephone cables. When power cables are worked at relatively high temperatures they should not also carry a heavy drainage current which might cause over heating. Where such conditions prevail drainage is not employed, but insulating joints are used to break up the continuity of the lead sheaths.

(b) **Pipe Systems:** The early success of the drainage method in affording protection against electrolysis of lead-sheathed cables led to the proposal to apply the same method of protection to underground piping systems. The result has been that in some cases drainage has been applied to gas and water piping systems to a greater or lesser extent. Some of these installations are reported to be a success, while others are reported to have been attended with objectionable results.

It has been found that there are certain differences between the application of drainage to pipes and the application of drainage to cable sheaths. The principal difference that has been found is that the cable sheaths are electrically continuous and uniform conductors, while the pipes are generally non-uniform and sometimes discontinuous conductors, by reason of the joints. It is found that where current flows along a pipe and encounters a high resistance joint, part of the current will leave the pipe on the positive side of the joint to flow to some other underground conductor or to shunt around the joint and thereby cause electrolytic corrosion of the pipe on the positive side of the joint.

Another difference between lead-sheathed cables and piping systems is that the cables are relatively small and are contained in ducts, so that unless they are submerged they are not in direct contact with earth, except at infrequent points, whereas gas and water pipes form extensive systems and are buried directly in earth. It is found as a result of this that a drainage connection from an underground piping system generally causes very much larger currents to flow on the piping system than a drainage connection from an underground cable system.

In the application of the drainage system it has been found that unless all sub-surface metallic structures affected by stray currents have been bonded together in such a way that at every point where the different structures come into proximity to one anotherall are maintained at the same potential, damage to the unconnected structures has in certain instances resulted from a flow of current through earth from the structure of higher to that of lower potential, thus causing electrolysis of the former. As structures owned by different interests cannot be bonded together except by an agreement between the owners, this has frequently of itself made it impossible to apply a comprehensive drainage system to all structures, because of the impossibility of obtaining an agreement of all owners to allow connections to their structures, except on condition that another interest assume liability for any injury which may result from such connections.

Current flowing on piping systems which convey inflammable substances such as gas or oil constitutes a danger, as cases have been reported where stray currents on pipes have caused arcs which have ignited the gas or oil when an intentional or accidental break in the pipe has occurred. In other instances serious damage from explosions and fire has been caused by an arc due to the intermittent contact between pipes.

(c.) **Structural Steel.** In a number of installations special precautions have been taken to prevent stray current from reaching structural steel. Where in these cases such currents were found to reach the structure by means of pipes or other metallic connections, insulating joints have been placed in such connections, or these pipes or conductors have been carried on insulated supports. In some cases where flow of stray currents to a steel structure could not be entirely prevented, drainage connections from the structure to the railway negative return circuit have been installed to remove the stray current from the structure, and where there were expansion joints in the structure these have been bonded across by metallic conductors.

C. PATENTED PROTECTIVE SYSTEMS.

58. Foreign and Domestic Patents. There have been many patents taken out in this country and abroad within the last twenty years, covering systems of electrolysis mitigation. Reference may be had to Technologic Paper No. 52 issued by the Bureau of Standards, Washington, D. C.

D. ORDINANCES AND DECISIONS.

59. Ordinances. A number of cities have ordinances directed to the construction and operation of electric railways. The Committee, however, does not possess sufficiently definite information as to the extent to which they have been put into effect or the results secured to warrant it in stating any facts regarding them at present.

60. Decisions of Courts. While there have been several cases of electrolysis litigation in this country each of these has either been concerned only with certain phases of the subject or has been limited by local conditions, so that there are no leading decisions by courts in this country which define specifically the duties and rights of the several parties concerned.

IV. EUROPEAN PRACTICE.

A. GENERAL.

61. Personal Investigation Necessary. In the study of the practice followed in European countries in handling the problem of electrolysis, it appeared impossible to secure reliable and satisfactory information by mere correspondence and consultation of published reports and regulations; and further, since the important independent investigations made by American investigators several years ago were private and made from the standpoint of some special industry rather than from a comprehensive all-around point of view the necessity of an independent investigation was made evident.

The Chairman of this Sub-Committee, after consultation with its members and the General Chairman decided to visit several important European countries during the summer of 1914. He was accompanied by Mr. A. Maxwell, Testing Officer of The New York Edison Company, who was thoroughly conversant with electrolysis measurements and surveys. The effort to have the Bureau of Standards appoint a representative to join the visiting representatives failed on account of extensive engagements of the Bureau, but a consultation was held in Washington, and the field of inquiry and special points to be looked after were carefully discussed, and a list of classified questions prepared, so that as far as possible uniformity of system of investigation could be followed in all instances. Similar consultations were held with members of the main Committee. Information on important foreign cities and authorities, was received from Mr. H. S. Warren, also foreign papers, suggestions and references from Prof. Albert F. Ganz.

62. Countries Visited. The visiting Committee spent June and July in its investigation, covering Germany, Italy, France and England. In each country an effort was made to take measurements and collect data and surveys, also to interview the most prominent people in each branch of the different interests affected by the problem of electrolysis; in each case extended and often repeated conferences were held with the engineers most familiar with the details, either in their capacity of specialized consulting engineers or officials of corporations or public authorities directly concerned in the surveys, disputes, administrative measures, etc. relating to electrolysis.

The essential and characteristic results of the investigation are briefly outlined in the following paragraphs, classified by countries visited. The references and appendixes to this summary should be consulted for details of design, operation and statistical information.

B. GERMANY.

63. Laws and Ordinances. There are no specific statutory laws. The common law of most States prescribes that all the conditions under which a corporation is to operate must be prescribed in the original grant or for any extension of lines, and the law prescribes that due publicity be given to any request for a franchise or extension of lines, so as to enable all parties which may be affected to place on record any limitation, or possible damage they wish to be protected against, before the concession is granted to the applicant. Hence, a pipe owning company organized subsequently to the existence of an electric railway, could not claim damages for electrolysis from this electric railway unless the original franchise to the railway contained a clause regarding electrolysis damages from stray currents.

On the other hand, when the municipality undertakes the construction and operation of a tramway system, the pipe owning companies then in existence are deprived of the privilege of demanding that protection against possible future damages by electrolysis which would be accorded to them in the case of a new private railway company. The municipality does not assume legally the obligation to protect the existing interests against possible damages by electrolysis. The municipalities, however, both for their new railway constructions, as well as for new extensions of existing companies' railways, always prescribe that they be constructed and operated in accordance with existing technical standards.

The recommendations of the German Earth Current Commission are recognized as the existing technical standards regarding matters relating to electrolysis, and in this manner they have assumed almost the importance of law.

64. Commission Recommendations. The German Earth Current Commission's recommendations adopted in 1910 by the German Electrotechnical Society prescribe the following:

In large cities, the maximum rail drop is to be limited, in the urban net-work and for a distance of 2 km. beyond, to 2.5 volts and to 1 volt per km. beyond this central district. Exceptions are made for roads operating only a few hours a day. (It may be noted here that the maximum drop is interpreted to be the average maximum drop for the period of the normal day traffic, usually 18 hours in every 24 hours.) Bonds must not increase the resistance of tracks over 20%—must be tested yearly and when a connection shows a resistance higher than 10 meters of rail it must be repaired. Connections to pipes are prohibited. Bare feeder returns are not allowed. Pilot wires are prescribed.

Since these regulations were promulgated from 20 to 30 installations in Germany (some municipally owned and some privately) have taken steps to bring up their standard of construction to meet these regulations.

65. Construction. In large cities, like Berlin, the railways are supplied by a great number of combination light and railway substations feeding limited districts, entailing relatively small positive line drops of potential. In some cases like Berlin, each feeding point is fed by positive and negative cables of equal cross-section.

Insulated returns with balancing resistances are predominantly used in Germany, though there are a few installations with negative boosters, like Danzig, where, however, insulated returns with balancing resistances as well as boosters are used.

There are very few large installations using bare returns. The "drainage system" was used in Aachen but it is now a subject of litigation.

66 Conditions. In general the electrolysis conditions throughout Germany are now very satisfactory. In the past the majority of troubles have been on gas and water pipes, or at least these have received more attention in the reports. The railway experts expressed the opinion that the regulations were too stringent; the gas and water pipe experts expressed the opinion that the regulations were too lenient. The studies are made in the most excellent technical manner and the conclusions arrived at appear to be practicable and reasonably acceptable to all parties concerned.

Measurements were made by the Sub-Committee of one large installation and it was found that the maximum drops in rails were well within the limits prescribed by the German regulations. More extended measurements were omitted, depending for other information on the surveys made by the German Earth Current Commission.

C. ITALY.

67. Laws and Ordinances. The Government has not enacted any law affecting the operation of electric railways in relation to electrolysis problems, nor has any municipality issued regulations on the subject.

68. Construction. Bare returns are generally used, in large installations.

69. Conditions. From a survey made in a city six years ago, it was found that the maximum differences of rail potential were as great as 17.5 volts between station and distant points about three miles away. In this installation they had not received complaints of serious damages by electrolysis, except a few gas service pipes, though the railroad itself had experienced some difficulties on water pipes at one of its yards.

Some of the larger systems in important cities are alive to the situation and are following with interest the developments in other countries.

In general, troubles from electrolysis have been considered insignificant in the Italian practice.

D. FRANCE.

70. Laws and Ordinances. A Ministerial Decree of March 21, 1911, prescribes that the maximum voltage drop in rail returns of *electric tramways* shall not exceed *one volt per kilometer*, except in locations where there do not exist metallic masses in the neighborhood of the tracks, where the limit may be exceeded. No definition is given of the time element in the measurement of the maximum drop, except by stating that it must be the average during the normal passage of the cars. The same decree prescribes that the bonds must be kept in the best possible condition, that the resistance of each must not be greater than 10 metres of normal rail and that periodic tests must be made and recorded on a register which must be subject to inspection on the call of the control service. The return feeders must be insulated.

71. Construction. While the Government regulations prescribe the use of insulated returns, we were informed that in general the practice is to connect the rails to the negative bus and to rarely use insulated returns. Noticeable exceptions are the Paris conduit system tramways using complete insulated returns, and the Paris Nord-Sud Subway Company operating a three wire system with the rails as neutral.

72. Conditions. The investigation was somewhat limited in France. In general serious electrolysis troubles were found only in a few situations, either created by installations of heavy traffic electric lines, or by peculiar conditions not readily explainable. The maximum drop of potential between pipe and rail measured by this Committee was about 6 volts at a location where trouble has been persistent and serious.

Damage has been caused in the past to gas pipes in Paris during the period of transformation of the old two-wire, three-wire and five-wire systems of electric light distribution, but all of these troubles were only of temporary character and were promptly remedied as soon as discovered.

Many suits (about twenty) for electrolysis damages are being tried in Paris. On account of the situation created by these suits the Paris municipality and the government have recently appointed a Commission to investigate the subject and make recommendations regarding the electrolysis situation in the City of Paris.

E. ENGLAND.

73. Laws and Ordinances. The Board of Trade regulations prescribe that the maximum rail drop shall not exceed seven volts. In practice the Board takes as the voltage drop the mean between the average and the momentary maximum values for the period of a schedule run at time of maximum traffic, exclusive of exceptional occasions like athletic games, etc. The periods assumed vary from 15 to 30 minutes. The regulations also contain other requirements, prescribing measurements of track leakage, etc.; in actual practice, however, little attention is paid to any other requirements as long as the seven volt over-all rail drop is not exceeded.

74. Construction. Whenever the resistance of the rails would give a drop in excess of seven volts, insulated return feeders with resistances, or negative boosters are used; the latter more extensively than in any other country.

75. Conditions. The sub-committee found that in all the several cities visited the Board of Trade regulations were met well within the limits. In fact, on the average the maximum drops measured in all large cities visited in the months of June and July were about two volts.

The Board of Trade regulations are not considered onerous by any of the railway engineers we consulted. All authorities representing the pipe owning companies, the railways, the State telegraph and telephone and the Board of Trade were unanimous in stating that the electrolysis situation on the properties under their respective control was entirely satisfactory.

The only question raised, and this only by a limited number of pipe owning entities, is whether the electric railways should not be held legally responsible for any damages, even when they comply with the Board of Trade regulations. Two or three attempts have been made to have a law passed by the Parliament to this effect, and two or three pipe exhibits have been repeatedly presented to prove electrolysis damages, but the Parliament refused to act.

The seven volt limitation is considered somewhat of a haphazard empirical measure formulated many years ago, but having given good results it is considered good enough, though it is conceded that some more rational measure could probably now be devised to replace it. However, no demand was discovered for a change on the part of anyone concerned.

F. SUMMARY AND CONCLUSIONS.

76. Germany through voluntary co-operation has probably remedied the former dangerous electrolysis conditions in all of its important systems. The instrumentality of agreements on definite technical standards was sought in preference to legislation for different states.

Italy will probably give more consideration to the subject of electrolysis whenever the general conditions will permit.

France has not been as successful in bringing prompt results through legislation, as has Germany through technical co-operation.

England, which has had the benefit of Government regulation for many years, has now no electrolysis troubles nor disputes.

In Germany and England, the subject of electrolysis has received extensive study and consideration. The attached typical abstracts of reports of the German Earth Current Commission and the appendix of the detail report of the Sub-Committee are evidence of the methods followed and the satisfactory results obtained abroad by adopting the following measures:

1st. Maintenance of good bonding.

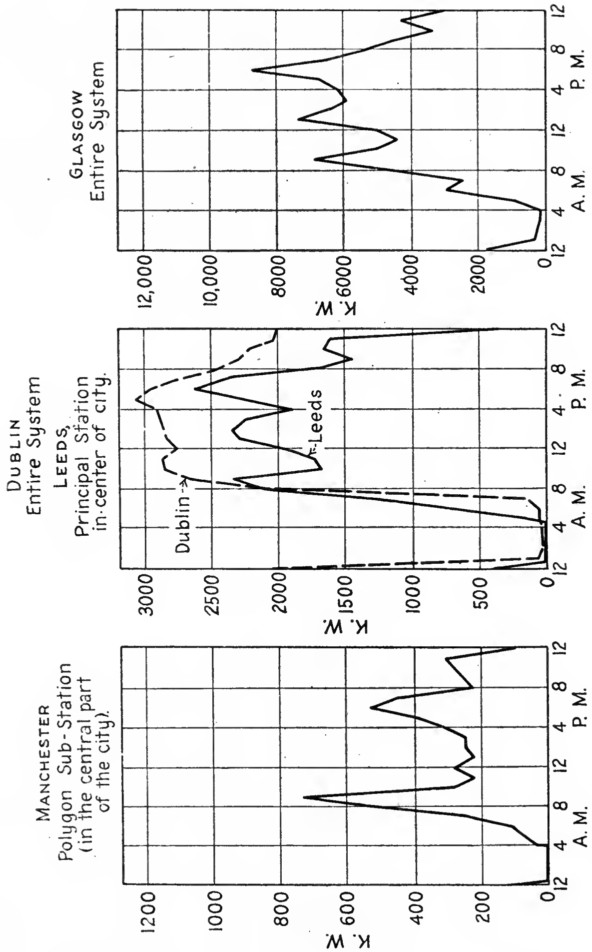
2nd. Elimination of intentional contacts, and liberal separation, whenever possible, of pipes and rails.

3rd. Avoidance of bare copper returns and use of insulated returns in all installations where the conductivity of the rail alone would give a too great maximum rail drop.

4th. Use of insulated returns with balancing resistances, or to a lesser extent "boosters," for the purpose of maintaining equality of rail potential at the feeding points of all feeders.

5th. Small feeder drops and frequent substations to give close line regulation.

77. Application to American Conditions. This study has not been made with the object of arriving at definite recommendations, but to point out that disputes on account of electrolysis troubles have been prevalent in the past in all countries before systematic cooperative studies or regulations had been applied, notwithstanding the fact that the mode of life and distribution of population and industries are more favorable than in American cities. The average weight of cars in foreign cities is essen-



Typical Load Curves, Electric Railways, - United Kingdom

Figure 6

tially less than in most American cities of the same population and the tramway traffic and loads per capita may be one-fifth or even less in Europe than in America. A city like Berlin with over 2,000,000 inhabitants handles all its transportation with a maximum load of about 30,000 k.w. (Chicago and the adjacent territory with 2,600,000 population requires a maximum load of about 200,000 k. w.) Manchester with a population of 1,250,000 and Glasgow with 1,000,000 have traction loads of 11,000 k. w. and 11,500 k. w. respectively. (Boston and the surrounding territory served by the same traction system has an approximate population of 1,150,000 and requires a power station capacity of 75,000 k. w.) Milan with a population of over 600,000 inhabitants has a traction load of approximately 8,000 k. w. and Nürnberg with 350,000 inhabitants uses only 1000 k. w. (The city of Worcester, Mass. with a population of approximately 160,000 requires power station capacity of 7,500 k. w.) These comparisons should not be taken as a definite index to comparative electrolysis conditions since many other factors are involved.

Other similar statistics for smaller places are given in Figure 6, and they should be taken in consideration in applying to this country the results of this investigation of foreign practice. Regardless of the degree of improvement which economical limitations may make permissible to accomplish in local situations, the fundamentals for the solution of the electrolysis problem evolved abroad merit the most careful study to ascertain their possible application to American conditions.

G. REGULATIONS ADOPTED AND PROPOSED.

78. Germany—Earth Current Commission's Recommendations. Recommendations of the German Earth Current Commission as adopted by the Gas, Water and Railway Interests of Germany.

> Regulations for the protection of gas and water mains from the electrolytic action of currents from direct current Electric Railways which use the rails as a return.
>
> Accepted for two years at the yearly meeting of 1910 and for a further two years at the yearly meeting of 1912.
>
> Published in the *Electrotechnische Zeitschrift* 1910, page 491, and 1911, page 511.

Section 1. Application of Rules.

The following rules govern the installation of direct current railways or sections of direct current railways which use the rails for carrying the return current. Unless otherwise mentioned the herein given admissible potential values should be adhered to when laying out new railways. For determining the resistance of a line, the rails only must be taken into account as current carrying mediums and the assumed resistance of the rails, as well as the assumed percentage increase of resistance due to the bonding, must be stated.

These values must not be exceeded, either when making the necessary calculations or by the plant when in actual normal operation.

These rules do not apply when railways are laid with special track or when the rails are laid on wooden sleepers, in which case there is generally an air clearance between the rails and the stone ballast. But the rules do apply if this air clearance does not exist, as at grade crossings, unless an equivalent insulation is provided for locally. Further, these rules do not apply to railway lines which do not approach closer than 200 meters to an underground pipe network.

Explanation.*

The regulations apply only to direct current railroads or sections of such, using the rails as conductors. Railroads not using the rails as conductors are eliminated from the start, because the same do not send any currents into the earth and therefore cannot have any damaging influence on the pipes. According to the experience reached so far, alternating current seems to have very little effect, so that any extension of these rules to cover also alternating current railways does not seem justified. At any rate, the conditions produced by alternating current railways are not yet sufficiently understood to allow of establishing any restrictions in regard to their equipment and operation for the protection of pipes.

In case a railroad is operated partly with direct current and partly with alternating current, these regulations apply only to those sections the rails of which carry direct current. The fixed upper limits of permissible potentials apply to the design of the plant, unless otherwise stated, and in the

*Note: This explanation and the others following are included in the German Earth Current Committees Recommendations.

calculations only the rails and the bonds are to be considered as far as the conductivity and the resistances of the conductors are concerned. The assumed resistance of the rails and the increase of same by the resistance of the bonds is to be stated, and such limiting values are not to be exceeded either by calculations or in practice.

The earth as a shunt is not considered. Through contact of the rail network with the ground, a part of the current passes into the ground and the potentials of the rail network are thereby lowered as compared with a case of perfect insulation from the ground, the effect becoming greater, the more the current passes into the ground. It is, therefore, not correct to take the differences of potentials as found immediately after the construction of a rail network as a basis for estimating the safety against damaging influences, but it is necessary to go back to the first cause, that is to say, the differences of potential as they would be if the rails were completely insulated.

This rule allows of an exact calculation of the conditions during the design of the plant without any uncertain and varying values for different localities. The limit values are not to be exceeded either during the calculations or at the actual practical test. The method of the practical test will be discussed in Section 3. The projection of the plant is, therefore, to be based on assumptions as correct as possible with regard to the resistance of the rail, the cables, and the consumption of current, and it is advisable to consider also a later increase of the traffic.

Railroads, the rails of which are insulated on special roadbeds, generally have such a great resistance against the earth that passage of current into the ground to be considered as dangerous to pipes does not occur. Higher potentials, therefore, are permissible for such railroads, assuming that a sufficient insulation is provided for also on grade crossings, etc.

As a means to this end are to be considered:

Insulating strata between rails and ground, for instance, tar paper, which must extend on all sides sufficiently beyond the place in question; or the surrounding of the pipes with insulating material. Such places are to be inspected from time to time to ascertain the effect of such insulation.

For the exemption from these regulations the laying of the rails on a special roadbed is required, because it is only in this way that a permanent insulation can be reached and maintained. About the details of the system of insulation to be used, no rules were issued. A lasting insulation is to be guaranteed by the way in which the rails are laid. The laying of rails on wooden ties as mentioned above is intended as an example only. At any rate to secure satisfactory insulation it is imperative that the rails be nowhere in contact with the moisture of the ground, as this greatly favors the passage of the current into the ground.

Tracks which are at all points at least 200 m. distant from any pipes are exempt, because any current coming over such an extended area spreads to such a degree that its density cannot possibly be harmful. In this respect concession has been made to long outlying railway lines because the subjection of such to these regulations would entail great economic disadvantages in certain cases. The maintenance of good conductivity on such outlying sections is to be strongly recommended so as to prevent the return currents from reaching a dangerous density where such sections join the rails of an inner rail network, *i.e.*, a density exceeding the limit given in Section 5.

Section 2. Rail Conductors.

All rails serving as return conductors should be built with regard to this requirement, should be made as good conductors as possible and should always be kept in good order.

The percentage of increase of the resistance of a given length of track due to the bonding should not exceed the value assumed when laying out the railway, and must not be more than 20% more than the resistance of the same length of track if the rails were without joints and of the same cross section and the same specific conductivity. On laying out a railway line consisting of main and auxiliary rails, the combined cross section of both rails can only be taken into account when determining the resistance of the track, provided the auxiliary as well as the main rails are properly bonded and cross bonded.

At rail crossings and at switches, the rails must be well bonded by special bridge bonds.

On single tracks as well as on lines where several tracks are lying side by side the rails must be efficiently cross bonded and these cross and bridge bonds must have a conductivity at least equal to a copper conductor of 80 square millimeters.

At all movable bridges or similar structures which necessitate an interruption of the rails, special insulated conductors have to be provided which secure a continuous connection between the two rail ends. In such cases, the voltage drop at average load must not exceed 5 millivolts for each meter distance between the interrupted rails.

All current carrying conductors which are connected to the rails, must be insulated from earth, excepting short connections such as bonds, cross-bonds and bridge-bonds at switches and turntables. If such bonds are laid not deeper than 25 centimeters into the earth, they may be bare conductors.

Explanation.

The first condition for the reduction of stray currents and for the effectiveness of all the proposed precautionary measures, is the good conductivity of the tracks and the maintenance of this conductivity. High resistances of the single sections cause an increase of the current passing into the ground. The maintenance of the good conductivity of the rails also is to the economic interest of the railroad, because a bad conductivity will, under certain circumstances, cause loss of energy.

It is not desirable to issue rules concerning the cross-sections of rails or for the conductivity of the steel because the cross-section and the chemical composition of the steel are both determined by mechanical considerations; the conductivity is dependent on the composition of the steel, while the conductance of the rail depends on both the conductivity and the profile.

The resistance of a rail network is widely influenced by the quality of the electrical connections of the rails at their joints.

The rules do not recommend one or another system of connections at the joints, but give data covering the permissible increase of the resistance by such connections.

In consideration of the varying resistance of rails of different profile, it is not possible to establish a uniform permissible resistance for a bond, but the permissible increase of the total resistance of a section by all the bonds is given. This increase must not be over 20%. Inside of these limits the designing engineer may assume any increase of the resistance by the bond, but it must be considered that the increase assumed must be permanently maintained later on (Compare Sections 6 and 3).

It will be well to assume during the design of the plant, the increase of resistance of the bonds as very near the permissible limit. This is very important when shorter rails are to be used, with the consequent greater number of joints, the maintenance of which is correspondingly more difficult and, therefore, an increase of resistance through deficient bonds to be expected. The conductivity of rails is to be ascertained on a number of samples before the rails are laid, so as to have a guarantee that the calculated resistance will correspond to the resistance of the finished network.

The measurement of the resistance is made by measuring the current and the potential on a rail as long as possible and insulated from its supports; the potential terminals should include a part of the circuit between the current contacts and they should be at least of 0.5 meter distant from these current contacts. A simple calculation gives the conductivity of the rail by using the value shown by ammeter and voltmeter. The conductivity of the rails now in use is generally found to be between 4 and 5.5 Siemens.

In cases where main and auxiliary rails are to be used and where the combined cross-section of both is taken into calculation, the conductivity of the auxiliary rail also is to be measured as the same may differ considerably from the conductivity of the main rail.

At crossings and switches a loosening of the rail connections will take place caused by the vibrations brought about by the passage of the rolling stock, for which reason such places are to be bridged specially by electrical conductors. The cross connections serve the purpose of eliminating differences of potentials between tracks running side by side and also to insure a good metallic connection between the rails on one side of a track in the case of a temporary low conductivity of single joints or interruptions.

It seems advisable in consideration of the different length of rails, not to give an absolute distance between the cross-connections, but to establish their number by the number of joints. The bonds and cross-connections may be of any material as long as their conductivity reaches at least that of a copper connector of 80 square mm. For the connection of interrupted tracks, as for instance at movable bridges, insulated cables are required because of the presence of water or other substances in the soil, which highly favor the passage of currents into the ground. The highest permissible drop in potential at average load has been fixed at 5 millivolts per meter distance between the places of interruption, to insure a small difference of potential between these points.

Furthermore care is to be taken that the tracks in a movable bridge are in good contact with the tracks on both sides of it. The following is an example of the calculation of a cable bridging across the gap.

When the distance between the tracks at the point of interruption equals 30 meters, the permissible difference of potential therefore is 5 × 30 which equals 150 millivolts. The current to be carried across is assumed to be 120 amperes and the length of cable 30 meters. Assuming a specific resistance of 17.5 milliohms per meter and square millimeter, the resulting cross-section is:

$$q = \frac{17.5 \times L\,I}{e} = \frac{17.5 \times 30 \times 120}{150} = 420 \text{ sq. mm.}$$

Inasmuch as the increase of the surface contact between the conductors and ground results in an increase of the current passing from the conductors into the ground, the conductors connected to the rails, especially those lying deep enough to come into contact with the moisture of the ground, are to be insulated conductors. Only short connections such as jumpers on crossings and switches, are exempt from this rule on account of the same not lying deeper than 25 cm. under the surface, which means that they hardly come into contact with the moisture of the ground. The increase of surface of the contacts with the ground by these conductors, is too small in proportion to the total surface of the rail network to cause any apprehension regarding the currents passing into the ground.

Section 3. Rail Potential.

A railway network is divided into two sections, first, the open road connecting the various townships, and second, the urban network.

In the urban network and for a distance of 2 km. beyond, the voltage drop between any two rail points should never exceed 2.5 volts when the line is working under normal conditions, and the drop in the rails for each kilometer of open road should not exceed 1 volt. Occasional night cars are not to be considered in determining the average load.

In townships through which only a single line is run, without local rail network, the total voltage drop in the rails must not exceed 2.5 volts from end to end of the township's pipe network.

Any apparatus which is supplied with current and which is connected to the railway network must not increase the voltage drop above the stated limits.

If various railway systems are connected together either through the medium of the rails or through the power station, each system must fulfill the above conditions. A rail system in a township with an independent pipe network has to comply with the above regulations also.

Exceptions from these rules in regard to the voltage drop in a railway network are admissible if local conditions and service necessitate and justify such exceptions. If, for instance, the service—as is the case in freight yards—covers only a small portion of the day, the above limits of rail drops may be exceeded. In yards with a service up to 3 hours daily, double the above values are permitted, and with a service up to one hour, four times the above values are allowed.

Explanation.

As mentioned in Section 1, the rail network is to be considered as insulated from the ground, so that the earth as a shunt is not considered.

The resistances of the single sections are to be calculated from the resistance of the rails under observance of the rules in Sections 1 and 2.

For the calculation of the potentials the value of the average current is to be used, as the magnitude of electrolytic decomposition of the pipe metal depends on the quantity of current, that is to say, the product of current and time. The highest values have not to be considered for the calculations. To find the consumption of current the average service as per schedule has to serve as the base.

The average current consumed on single sections can be calculated from the number of car km. or ton km. to be covered, by using the value for the consumption of current which, according to experience, and in consideration of the local conditions, is used for one car km., or ton km.

But it is also permissible to distribute the consumption of current over the whole net in a way corresponding to the locations of the single trains at the time of the average load and to calculate for each train the consumption of current taking into consideration the weight of the cars, the speed and operating conditions (grades, stops).

In regard to the schedule, the difference between summer and winter service is to be considered. The increase at regular intervals, as for instance on Sundays, is to be taken into account. Small deviations from the schedule, as for instance, single night cars, or auxiliary cars, shall not be considered, because the first would reduce the average value out of proportion, and the frequency of the second cannot be estimated at the time of the calculations and otherwise are not of any appreciable influence on the final results.

It is impossible to get regulations embracing all conditions and possibilities and it is therefore necessary to consider all peculiarities of a plant during its projection. If there are any additional places connected to the rails, where current is used for stationary motors, station lighting, etc., these are to be considered.

After the drops in potential on the central sections have been tabulated, based on the above calculations, the distribution of the potential in the rail network can be found. In addition to the foregoing data for the calculation of the drop in potential on the single sections, consideration is to be given to the proposed return cables and, in case of a three wire system, to the direction of the current in the districts of different polarity.

Difference in potential between any two points of the rail network must answer the following conditions:

Around every individual pipe network (meaning a network not in metallic contact with any other network) and also around single pipes, a zone of two hundred m. is to be circumscribed and all tracks lying outside of this zone are not to be considered in connection with these regulations, as per last part of Section 1.

For each of the rail branches lying inside of these individual pipe networks, the following rules apply:

If there are any branches of the railroad inside of a pipe network, including the 200 m.-zones, a belt 2 km. wide is to be laid around the inner rail network. Inside this belt the potential of the rails between any different points must nowhere exceed 2.5 v., as long as no portion of the rails is more than 200 m. distant from the nearest pipe along its total length (Compare Fig. 7.).

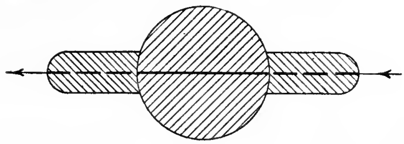
On the sections outside the 2.5 v. districts, the drop in potential must not exceed 1 v. per km. This applies to outlying sections which are shown in Fig. 7 by heavy dotted lines.

In the case of a railroad with no branches (country roads) and a pipe network, the drop in potential inside the pipe network must not exceed 2.5 v. (Compare Fig. 8). The rule establishing a drop of 1 v. per km. states that the current in the track must not exceed $\frac{1}{W}$, if W is the resistance of the track in ohms per km. For a uniform load of a section of L km. length and a uniform resistance, the permissible drop in potential $= \frac{L}{2}$ v. *i.e.* $\frac{1}{2}$ drop in one rail. The calculation of this drop also is based on the average load, according to the schedule.

Strict rules have been issued for the interior rail network with its many branches, as it mostly covers the same area as the pipe network. This has been done in consideration of the greater surface of contact between ground and rails and pipes respectively which increases the probability of a passage of current through the ground. The potential of 2.5 volts for this district has been judged permissible because, according to the results of previous investigations, it is to be assumed that this potential will not under ordinary conditions cause any danger to pipe lines beyond the practical limits. To avoid as much as possible any greater concentrations of ground and pipe currents at the outlying sections which immediately join the inner rail network, and where important parts of the pipe network often extend, strict rules have been issued covering the district inside the 2 km. belt around the inner rail network.

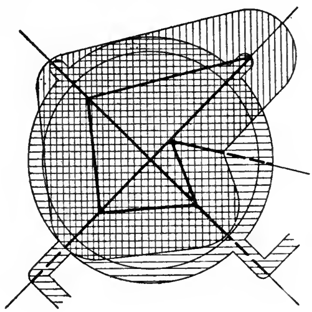
For the outlying section an economical advantage has been contemplated by limiting the drop in potential to 1 v. per km. Railroads interconnected by their rail networks or by a common power plant are to be considered as one system because such railroads influence each other, inasmuch as equalizing currents will flow between their rail networks.

Deviations in both directions from these potentials can be justified by certain circumstances—in case of especially good conditions of the ground, that is to say, in very dry dirt an increase of the potentials may be permissible. But even in such cases it is advisable to be cautious in allowing such an



District of interior pipe-network.
District of 200 m. around pipes with no branches.
Railroads in the 2.5 V. District.
Railroads in the 1 V-Km District.
Railroads with no Restrictions.

Figure 7



District of the pipe-network with the 200 m. belt surrounding it and the pipes with no branches.
District of the interior Rail-network with the 2 Km. belt surrounding it.
Railroads in the 2.5 V. District (shaded by both horizontal and vertical lines).
Railroads in the 1 V.-Km. District (shaded by horizontal lines).
Railroads with no restrictions (not shaded, or by vertical lines only).

Figure 8

increase, so as not to violate the rules as given in paragraph 5. Where the conditions are unfavorable, for instance, where moist ground of especially high conductivity prevails, it is advisable to remain below the limits. For railroads with brief daily operation concessions have been made because damage to the pipes depends upon the duration of the influence of the current so that, considering the short time of operation, even greater currents cannot cause any appreciable damage to the pipes.

For railroads of three hours daily operation double drop in potential is allowed, while for railroads of one hour operation, four times the drop is permissible. Wherever the rail network is not sufficient to carry the current without exceeding the permissible potential in the network, the whole plan for the return of the current must be altered, and improvement will be reached by providing return cables in which, if necessary, resistances or boosters may be inserted. The resistances should be variable so as to correspond with the variable conditions of service and operation. In cases where the railroad system is fed from several power plants a reduction of the drop in potential in the rails may be brought about by shifting the loads of the several power plants.

The arrangement of the cables and resistances can be made in so many different ways as to make a general rule for all cases impossible. It is recommended to investigate thoroughly the cases under observation, because considerable saving in the construction and operation of the plant may be achieved by a careful layout.

The keeping of the return points at the same potential is recommended as a precautionary measure but not required. The same offers a certain guarantee of the possibility to keep the difference of potential within the 2.5 V. limits.

Furthermore, the use of the 3 wire-system with the rails as a neutral conductor is worthy of consideration. In this system the difference of potential in the rails depends on the distribution of the positive and negative feeder districts. This distribution again depends on the local conditions of the plant, so that no general rules can be given in regard to it.

Alterations of the conditions of operation can be counteracted by switching the load to the positive or negative side of the system. The rules do not recommend any certain system, but leave it entirely to the projecting engineer to select the one best adapted to existing conditions. The damage to pipes takes place mostly at points of low potential on two-wire railroads, in the neighborhood of the return points; and on three-wire railroads, in the districts of negative feeders, because it is mainly here that the current leaves the pipes. It is advisable to place the return points of the negative feeder districts whenever possible in locations with dry ground of low conductivity and as far as possible from such pipe lines as are of importance for the water and gas supply.

The permissible limits of differences in potential in rails must not exceed, either according to calculations, or at the practical trial, the limits given in Section 1 of these rules. The measurement of the difference in potential is made by means of test wires as called for in Section 6. The measurements of differences in potential are limited to those points which, according to the calculations, come nearest to the established limits. Wherever long lines, as, for instance, telephone wires, are available, it is advisable to use them for these measurements, otherwise several test wires may be connected in series or temporary test lines may be installed: finally, the results of single measurements may be computed to reach the same final results. Only high resistance voltmeters should be used for these measurements so as to make the resistances of the test wire and contacts negligible. The pointers of these instruments should have the slowest movements and a good damper arrangement, so as to give good readings even under strong fluctuations. For all measurements only average values are considered. All measurements are to be extended over a full period of operation which results from the average frequency of trains.

Section 4. Resistance between Rail and Earth.

The resistance between ground and the rail which is used for carrying the return current should be kept as high as possible. When the conditions of the ground or the situation of the track are not favorable for this purpose, the resistance should be increased by a special effective insulation.

The rails or any conductor connected to the rails must not be in contact with the pipes or any kind of metal buried in the ground. Furthermore, care must be taken that the distance between the nearest rail and any metallic part of the pipe lines or connections to them which project above the ground or lie near the surface, be kept as great as possible, and should never be less than one meter.

Stationary motors, lighting installations or any other plant which receives current from a railway system which uses the rails for carrying the return current, must be connected to the rail network by means of insulated conductors. Excepted are short connections of not more than 16 square millimeters which are not deeper than 25 centimeters in the ground and which are at a distance of at least 1 meter from any part of a pipe network. These connections may be of bare metal. In order to increase the resistance between rail and ground it is recommended to use a bedding of high resistance and to provide good drainage, also to render the bedding water-tight to the roadbed for a sufficient width on both sides of the rail.

The use of salt for the melting of snow and ice, should be limited to cases of absolute necessity.

Wherever sufficient distance between the rail and such parts of the pipe line as project above the surface is not obtainable, it is advisable to change the pipe run, or where this is not possible, to use insulating strata (such as vitrified clay, masonry or wooden conduits, etc.).

Explanation.

The magnitude of currents passing into the ground depends not only on the potentials in the rail network, but also on the resistances between the rails and the pipes and on the resistances of the pipe lines themselves. It will always be of advantage to increase the resistance of the ground between the rails and the pipes. An artificial increase of the resistances of the pipe line can be achieved for instance, by the use of insulating flanges, couplings, etc. Aside from the technical difficulties of installing such insulating parts into gas pipes, and especially water pipes with a high pressure, and of insuring their lasting tightness, it would be difficult to provide these insulating pieces in the necessary numbers and to take care of their correct distribution. A wrong arrangement of the same will lead to an extraordinary concentration of currents at these insulations with consequent corrosion in these places. A greater part of the drop in potential between pipe and rail originally takes place in the roadbed as can be easily understood and it is therefore required to render this resistance as high as possible by the good insulation of the roadbed, good drainage, etc., and to maintain it thus.

In the same measure that the increase of the resistances between rail and pipe is recommended, the use of any means to reduce these resistances, is to be warned against. Such means to be considered are ground plates, connections of metals in the ground, and especially metallic connections between the rails and the pipes. The last will reduce the density of the current at the point of connection to the pipe, but they cause an increase of the pipe current and of the ground currents in general which may cause damage in other places, as, for instance, at interruptions in the pipe line or at crossings with other lines. Any local measure taken must be considered with regard to its effect on the pipes in other localities.

Metallic connections between different pipe networks also are to be judged from this viewpoint. Immediate contact of any parts of the pipe lines with the rails, or too close an approach, has the same effect as direct metallic connections and is, therefore, to be avoided. (By a re-location of rails or pipes or installation of insulating strata).

Especially in cases of stationary motors or lighting plants connected to the railroad system, there exists on the premises danger of an accidental or deliberate connection or contact with the pipe lines. It is, therefore, necessary to have strict rules regarding the return cables from such plants.

Section 5. Current Density.

The above rules are intended to prevent the destruction of the pipes by electrolysis. The rate of destruction is in direct proportion to the amount of current leaving the pipe.

Any pipe line where the current leaving the pipe exceeds an average density of 0.75 milliampere per square decimeter and where this current is due to a railway, may be considered endangered by this railway, and further preventive measures must be taken.

For railways with freight service when the service is of comparatively short duration, exceptions as already mentioned are permissible.

In cases where the current leaving or passing into the pipes changes its direction, the current passing into the pipe must be taken as nil when determining the average density, until further experience has been gained in this matter.

Explanation.

Inasmuch as a total elimination of all damages to pipes would be in most cases possible only at a disproportionately high cost, which would far exceed the cost of any possible damage to the pipes, it is necessary to allow a certain limited damage, that is to say, a damage which is of little practical importance and which does not noticeably shorten the life of the pipes. These rules have therefore been compiled on the basis of the average conditions, that is to say, such as are mostly met with, and it is to be expected according to previous experience that the damage done to pipe lines by the stray currents from electrical railways, generally will remain limited to the practical allowable limit wherever these rules are observed. Under exceptionally bad conditions, that is to say, under conditions which very much favor the origin of stray currents, greater corrosion of pipes in certain places can hardly be avoided, even if the limits of the drop in the potential in the rails, as laid down in Section 3, are not exceeded. It is, therefore, advisable to establish some measure for the elimination of immediate danger to the pipes.

For the judgment of the damage attributed to a railroad system the density of the current leaving the pipes and returning to the railroad system is indicative.

The density of the current at the pipe can be measured only after the completion of the plant. These measurements must be made during the time of operation, as per schedule, and as described in Section 3. The average density is important and is obtained from the computation of the results of several measurements, each of which follows a whole period of service.

Measurements of current density can be made, for instance, by means of a milliammeter and non-polarizable frame as designed by Prof. Haber. This frame contains two copper plates which are insulated from each other and which for the prevention of polarization are covered with a paste of copper sulphate and 20% sulphuric acid, over which a parchment, soaked with sodium sulphate is laid. The frame is filled with dirt except between the plates, and placed alongside the pipe at right angles to the assumed direction of the current and then covered with dirt. A very sensitive ammeter connected to the copper plates will indicate the current passing through the frame and the density of this current can readily be calculated by taking into account the surface of the copper plates inside the frame. Inasmuch as here also only average readings are to be considered, it is advisable to use an instrument with very slow period.

According to investigations made so far, absolute danger to the pipes results whenever the density of the currents leaving the pipes reaches the average value of 0.75 milliampere per square dcm. For railroads with small periods of operation an excess up to double and quadruple, respectively, the above value is permissible according to the rules laid down in Section 3.

Wherever the direction of the current changes, the currents entering the pipes are not to be considered in the calculations of the average density, inasmuch as it is not as yet established that such currents will add to the metal of the pipes. Wherever the average values are exceeded, especial precautionary measures are to be taken, the nature of which can be determined only by the local conditions. In many cases it is sufficient to protect a very limited section of the rail network, to which end the further reduction of the drop in the rails may not be necessary, but which may be attained by other means as, for instance, the re-location of short sections of tracks or pipes, or the artificial increase of the resistances between rails and pipes at such points.

In all cases the question arises whether the railroad is to be considered as the only cause of current concentration, as other causes may be found to be responsible for a part of the current on the pipes; for instance, bare neutrals or poor insulation in other electrical systems, the natural electrical elements resulting from the use of different metals in the pipe lines, or from different chemicals in solution in the ground. That part of the current which is attributable to the influence of the railroad can be determined by comparison with the measurements of the current during the period of no operation. In many cases the influence of the railroad can be judged from contemporaneous measurements of current density and the potential between pipe and rail. Under certain circumstances it is possible to find the degree of influence of the railroad and of other electrical plants operating at the same time, by establishing the course of the current in the ground. For this investigation electrodes that cannot be polarized are used as contacts from the test line to the ground. The measurements should preferably be made by the potentiometer method in order to eliminate drop at the electrodes due to the current flow, but this method is difficult in practice on account of the rapid fluctuations of the voltage. It will be sufficient in most cases to make the measurements with a voltmeter of very high resistance so that the current passing through the electrodes will be very small. It should be emphasized that such measurements should be made by experts only, as deviations from the right method which seem of no importance often give useless results.

Section 6. Control.

In order to be able to test the potential at the return points of the rail system of a given territory, pilot wires are to be connected to these points and carried to a central testing place.

Before a service may be increased the potential distribution in the rail network must be retested.

The rail bonds and bridge connections are to be retested once yearly by means of a suitable rail joint tester and must be arranged so that they fulfill the rules of Sections 1 and 2. Connections the resistance of which has been found greater than that of an uninterrupted rail of 10 meters length must be repaired to comply with these rules.

Explanation.

The control of the drop in potential in the whole network would be best assured by the installation of test wires from one of the buses to all points of probable highest and lowest rail potential, which arrangement admits of immediate measurement of potential between these points.

In certain cases, especially in existing plants, the installation of such test wires would involve great cost. Such test wires from all of the important rail points were not required; but it has been ruled that all points of the rail network, to which cables of the same district are now connected, are to be provided with test wires which have to run to some central point where readings of the differences of potentials between the return points can be taken.

Wherever the expense involved permits, it is recommended to install test wires not only to the return points but also to the points of highest rail potentials.

After permanent changes in the operation, the distribution of the potential in the rail network is to be investigated in the same way as after the inauguration of the plant, in order to ascertain whether the new conditions still correspond to the rules.

In case of temporary changes of short duration in the whole network or parts of the same as, for instance, occasionally some festival, change or repair of tracks, fairs, exhibits, etc., no special measures are to be taken because the short duration of the influence will cause no noticeable damage even when the limits of these rules are exceeded.

The yearly investigation of the rail joints, as required by the rules, is also to be recommended with regard to the reduction of losses of energy. For these measurements an apparatus may be used which allows of the comparison of the drop in potentials across the joint with one of the adjoining uninterrupted rails so that the measurement may be taken during the operation. Joints of a resistance higher than that of an uninterrupted rail of 10 m. length are immediately to be repaired. The total resistance, as found by the measurement of the single joints, must not exceed the value which has been assumed during the projection of the plant (compare Section 2, paragraph 2).

Should it result during operation that rail joints are of a higher resistance than that assumed in the designing it is permissible to abstain from a re-construction of the joints as long as the permissible difference of potentials in the rails is not exceeded, even with these higher resistances. The established limits of 20% increase of the resistance of the uninterrupted rail by the bonds must not be exceeded in any case.

79. France—Regulations by Minister of Public Works Circular and order of the Minister of Public Works (France) of March 21, 1911, establishing the technical conditions which electrical distribution systems must satisfy in order to conform to the law of June 15, 1906. (Pages 25-27)

Section III. Regulations Relative to the Construction of Structures for Electric Railways using Direct Current.[1]

DISTRIBUTION POTENTIAL FOR RAILWAYS.

Art. 27. The requirements of art. 3, paragraph 4; of art. 5 paragraph 26; 4 and 6 of art. 25, and of the first two sections of paragraph 3 of art. 31 do not refer to trolley wires, nor their supports, nor the other lines placed upon these supports, nor those not upon the public highway, nor those inaccessible to the public, if the potential between these conductors and ground is not greater than 1000 volts.

1. Electric traction projects using alternating current should be submitted to the Minister of Public Works in all cases where distribution is upon the public highway.

RIGHT OF WAY.

ART. 28. When the rails are used as conductors, all necessary measures should be taken to guard against the harmful action of stray currents, on metallic structures, such as the tracks of railways, the water and gas pipes, the telegraph or telephone lines and all other electric conductors, etc.

To this end the following regulations shall be applied:

1. The conductance of the tracks shall be known to be in the best possible condition, especially in regard to the joints, whose resistance should not exceed, in each case, that of 10 meters of the normal track.

The management is required to verify periodically this conductance and to place the results obtained on file, which shall be accessible to the administration upon demand.

2. The drop in potential in the rails, measured upon a length of track of 1 kilometer taken arbitrarily upon any section of the system, should not exceed an average value of 1 volt for the operating period of the normal car schedule.

3. The feeders tied into the track shall be insulated.

4. Where the tracks contain switches or crossings, the conductance shall be maintained by special work.

5. When the track crosses a metallic structure, it should be electrically insulated, as much as possible, throughout the length of the structure.

6. As long as no metallic structure is in the neighborhood of the tracks, a drop in potential greater than that fixed in paragraph 2 may be allowed, upon the condition that no damage will result, and particularly no trouble to telegraphic or telephonic communication, and none to railway signals.

7. The owner of the distribution system shall be required to make the installations necessary to enable the administration to verify the fulfillment of the provisions of this article; it should particularly provide, whenever necessary, for pilot

wires to be installed between designated points of the distribution system.

PROTECTION OF NEIGHBORING AERIAL LINES.

ART. 29. At all points where the lines feeding the traction system cross other distribution lines, or telegraph or telephone lines, the supports should be established with a view to protect mechanically these lines against contact with the aerial conductors feeding the traction system.

In all cases, measures shall be taken to prevent the trolley wire touching the neighboring lines.

80. England.—British Board of Trade Regulations. Regulations made by the Board of Trade under the provisions of Special Tramways Acts or Light Railway Orders authorizing "lines" on public roads; for regulating the use of electrical power; for preventing fusion or injurious electrolytic action of or on gas or water pipes or other metallic pipes, structures or substances; and for minimising as far as is reasonably practicable injurious interference with the electric wires, lines, and apparatus of parties other than the Company, and the currents therein, whether such lines do or do not use the earth as a return.

First made, March, 1894.
Revised, April, 1903.
Further revised, August, 1904.
Further revised, May, 1908.
Further revised, April, 1910.
Further revised, September, 1912.

REGULATIONS.

1. Any dynamo used as a generator shall be of such pattern and construction as to be capable of producing a continuous current without appreciable pulsation.

2. One of the two conductors used for transmitting energy from the generator to the motors shall be in every case insulated from earth, and is hereinafter referred to as the "line"; the other may be insulated throughout, or may be uninsulated in such parts and to such extent as is provided in the following regulations, and is hereinafter referred to as the "return."

> The Board of Trade will be prepared to consider the issue of regulations for the use of alternating currents for electrical traction on application.

3. Where any rails on which cars run or any conductors laid between or within three feet of such rails form any part of a return, such part may be uninsulated. All other returns or parts of a return shall be insulated, unless of such sectional area as will reduce the difference of potential between the ends of the uninsulated portion of the return below the limit laid down in Regulation 7.

4. When any uninsulated conductor laid between or within three feet of the rails forms any part of a return, it shall be electrically connected to the rails at distances apart not exceeding 100 feet by means of copper strips having a sectional area of at least one-sixteenth of a square inch, or by other means of equal conductivity.

5. (a) When any part of a return is uninsulated it shall be connected with the negative terminal of the generator, and in such case the negative terminal of the generator shall also be directly connected, through the current-indicator hereinafter mentioned, to two separate earth connections which shall be placed not less than 20 yards apart.

(b) The earth connections referred to in this regulation shall be constructed, laid and maintained, so as to secure electrical contact with the general mass of earth, and so that, if possible, an electromotive force, not exceeding four volts, shall suffice to produce a current of at least two amperes from one earth connection to the other through the earth, and a test shall be made once in every month to ascertain whether this requirement is complied with.

(c) Provided that in place of such two earth connections the Company may make one connection to a main for water supply of not less than three inches internal diameter, with the consent of the owner thereof and of the person supplying the water, and provided that where, from the nature of the soil or for other reasons, the Company can show to the satisfaction of the Board of Trade that the earth connections herein specified cannot be constructed and maintained without undue expense the provisions of this regulation shall not apply.

(d) No portion of either earth connection shall be placed within six feet of any pipe except a main for water supply of not less than three inches internal diameter which is metallically connected to the earth connections with the consents hereinbefore specified.

(e) When the generator is at a considerable distance from the tramway the uninsulated return shall be connected to the negative terminal of the generator by means of one or more insulated return conductors, and the generator shall have no other connection with earth; and in such case the end of each insulated return connected with the uninsulated return shall be connected also through a current indicator to two separate earth connections, or with the necessary consents to a main for water supply, or with the like consents to both in the manner prescribed in this regulation.

(f) The current indicator may consist of an indicator at the generating station connected by insulated wires to the terminals of a resistance interposed between the return and the earth connection or connections, or it may consist of a suitable low-resistance maximum demand indicator. The said resistance, or the resistance of the maximum demand indicator, shall be such that the maximum current laid down in Regulation 6 (I) shall produce a difference of potential not exceeding one volt between the terminals. The indicator shall be so constructed as to indicate correctly the current passing through the resistance when connected to the terminals by the insulated wires before-mentioned.

6. When the return is partly or entirely uninsulated the Company shall in the construction and maintenance of the tramway (a) so separate the uninsulated return from the general mass of earth, and from any pipe in the vicinity; (b) so connect together the several lengths of the rails; (c) adopt such means for reducing the difference produced by the current between the potential of the uninsulated return at any one point and the potential of the uninsulated return at any other point; and (d) so maintain the efficiency of the earth connections specified in the preceding regulations as to fulfill the following conditions, viz.:

(I) That the current passing from the earth connections through the indicator to the generator or through the resistance to the insulated return shall not at any time exceed either two amperes per mile of single tramway line or five per cent of the total current output of the station.

(II) That if at any time and at any place a test be made by connecting a galvanometer or other current-indicator to the uninsulated return and to any pipe in the vicinity, it shall always be possible to reverse the direction of any current indicated by interposing a battery of three Leclanche cells connected in series if the direction of the current is from the return to the pipe, or by interposing one Leclanche cell if the direction of the current is from the pipe to the return.

The owner of any such pipe may require the Company to permit him at reasonable times and intervals to ascertain by test that the conditions specified in (II) are complied with as regards his pipe.

7. When the return is partly or entirely uninsulated a continuous record shall be kept by the Company of the difference of potential during the working of the tramway between points on the uninsulated return. If at any time such difference of potential between any two points exceeds the limit of *seven volts*, the Company shall take immediate steps to reduce it below that limit.

8. The current density in the rails shall not exceed nine amperes per square inch of the cross sectional area.

9. Every electrical connection with any pipe shall be so arranged as to admit of easy examination, and shall be tested by the Company at least once in every three months.

10. The insulation of the line and of the return when insulated, and of all feeders and other conductors, shall be so maintained that the leakage current shall not exceed one hundredth of an ampere per mile of tramway. The leakage current shall be ascertained not less frequently than once in every week before or after the hours of running when the line is fully charged. If at any time it should be found that the leakage current exceeds one-half of an ampere per mile of tramway the leak shall be localised and removed as soon as practicable, and the running of the cars shall be stopped unless the leak is localised and removed within 24 hours. Provided that where both line and return are placed within a conduit this regulation shall not apply.

11. The insulation resistance of all continuously insulated cables used for lines, for insulated returns, for feeders, or for other purposes, and laid below the surface of the ground, shall not be permitted to fall below the equivalent of 10 megohms for a length of one mile. A test of the insulation resistance of all such cables shall be made at least once in each month.

12. Any insulated return shall be placed parallel to and at a distance not exceeding three feet from the line when the line and return are both erected overhead, or eighteen inches when they are both laid underground.

13. In the disposition, connections, and working of feeders, the Company shall take all reasonable precautions to avoid injurious interference with any existing wires.

14. The Company shall so construct and maintain their system as to secure good contact between the motors and the line and return respectively.

15. The Company shall adopt the best means available to prevent the occurrence of undue sparking at the rubbing or rolling contacts in any place and in the construction and use of their generator and motors.

16. Where the line or return or both are laid in a conduit the following conditions shall be complied with in the construction and maintenance of such conduit:

(a) The conduit shall be so constructed as to admit of examination of and access to the conductors contained therein and their insulators and supports.

(b) It shall be so constructed as to be readily cleared of accumulation of dust or other debris, and no such accumulation shall be permitted to remain.

(c) It shall be laid to such falls and so connected to sumps or other means of drainage, as to automatically clear itself of water without danger of the water reaching the level of the conductors.

(d) If the conduit is formed of metal, all separate lengths shall be so jointed as to secure efficient metallic continuity for the passage of electric currents. Where the rails are used to form any part of the return they shall be electrically connected to the conduit by means of copper strips having a sectional area of at least one-sixteenth of a square inch, or other means of equal conductivity, at distances apart not exceeding 100 feet. Where the return is wholly insulated and contained within the conduit, the latter shall be connected to earth at the generating station or sub-station through a high resistance galvanometer suitable for the indication of any contact or partial contact of either the line or the return with the conduit.

(e) If the conduit is formed of any non-metallic material not being of high insulating quality and impervious to moisture throughout, the conductors shall be carried on insulators the supports for which shall be in metallic contact with one another throughout.

(f) The negative conductor shall be connected with earth at the station by a voltmeter and may also be connected with earth at the generating station or sub-station by an adjustable resistance and current-indicator. Neither conductor shall otherwise be permanently connected with earth.

(g) The conductors shall be constructed in sections not exceeding one-half a mile in length, and in the event of a leak occurring on either conductor that conductor shall at once be connected with the negative pole of the dynamo, and shall remain so connected until the leak can be removed.

(h) The leakage current shall be ascertained daily, before or after the hours of running, when the line is fully charged, and if at any time it shall be found to exceed one ampere per mile of tramway the leak shall be localised and removed as soon as practicable, and the running of the cars shall be stopped unless the leak is localised and removed within 24 hours.

17. The Company shall, so far as may be applicable to their system of working, keep records as specified below. These records shall, if and when required, be forwarded for the information of the Board of Trade.

Number of cars running.

Number of miles of single tramway line.

Daily Records.

Maximum working current.

Maximum working pressure.

Maximum current from the earth plates or water-pipe connections(vide Regulation 6 (I)) where the indicator is at the generating works.

Fall of potential in return (vide Regulation 7).

Leakage current (vide Regulation 16 (h)).

Weekly Records.

Leakage current (vide Regulation 10).

Maximum current from the earth plates or water-pipe connections (vide Regulations 6 (I)) where a maximum demand indicator is used.

Monthly Records.

Condition of earth connections (vide Regulation 5).

Minimum insulation resistance of insulated cables in megohms per mile (vide Regulation 11).

Quarterly Records.

Conductance of connections to pipes (vide Regulation 9).

Occasional Records.

Specimens of tests made under provisions of Regulation 6 (II.)

Board of Trade,
7, Whitehall Gardens, S. W.
September, 1912.

81. Spain—Electric Legislation. Law of March 23, 1900.

Article 50. To prevent the return current of electric tramway lines from exercising any electrolytic effects, the following measures shall be taken:

(1) The rails of each one of the tracks are bonded by welding or by connections formed of short copper cables, or of equivalent cables made of some other metal, the section of which having to exceed 100 square millimeters per track, and shall be made as large as possible.

(2) At intervals of 100 meters, or at shorter distances, the tracks shall be cross-bonded.

(3) In case the official inspector should deem it necessary, a cable will have to be stretched in every line, which will have to be intimately connected with both tracks; and

(4) The dimensions of all cables and wires constituting such system will have to be calculated upon a basis that the potential difference between the generator terminals and the point of the tracks remotest from them will not exceed an amount of seven volts.

H. SUMMARY OF EUROPEAN CONDITIONS.

Conditions in Germany, Italy, France and England as Reported to the Visiting Committee by Various Authorities in these Countries.

82. Present Electrolysis Conditions.

Germany. Considerable damage was found in many cities prior to the application of the Earth Current Commission's Regulations; in one case service pipe trouble occurred as often as once a month. Generally, however, extensive damage was not known until it was revealed by investigation; thus, many of the cities which were surveyed by the Commission, and where more or less corrosion was found, had previously reported no damage.

In general, the pipe owning interests stated that the situation was such that the work of the Earth Current Commission was urgently needed. Some railway engineers held that a considerable amount of corrosion ascribed to stray railway current was in fact due to other sources, or to self-corrosion.

Many very thorough tests have been made in Germany, and a large majority of these have shown that corrosion was being produced by stray railway currents.

The more prosperous companies and municipalities spent money for improvements after the publication of the Regulations of the Earth Current Commission. Exact information was not available regarding the number of places where changes had been made, but the best information indicated that the number was between 20 and 30. Of these, about 100,000 marks each was spent in Danzig, Strassburg and Erfurt, re-arranging the resistances in existing return conductors, and Dresden was engaged in insulating the existing bare conductors, and generally, the most important cities were rapidly improving their return circuit conditions.

The present conditions in Germany are considered satisfactory where the electric railways have conformed to the Commission Regulations, or where conditions were already equally good; in other cases the conditions are considered to be unsatisfactory. No cases of extensive damage to cable sheaths were found.

Italy. Very little damage, if any, is known in Italy, and the conditions are said to be satisfactory. This favorable report is based on the absence of complaints.

France. Outside of Paris, there is little damage caused by tramway systems, which generally observe a one volt per kilometer rail drop limit, contained in regulations issued by the Ministry of Public Works. No adequate or complete tests have been made in France, although some testing has been done in Paris following the development of trouble.

In Paris, 60 to 70 cases of damage to pipes have been found in a year, and the actual minimum cost of repairs was estimated to be 60,000 francs; however, it was held that the paramount consideration was the danger to security of service, since nearly all cases caused losses in buildings, although there were no explosions.

At least 30 to 35 per cent of the total number of cases reported were due to re-arrangement of the Edison two-wire and three-wire mains; such troubles are local and temporary, while in other cases the troubles are persistent.

A very considerable amount of damage in Paris is due to the "Metropolitan" subway system, which claims exemption from the one-volt per km. rule, not being a tramway system. With this exception, conditions in France are said to be generally satisfactory.

England. Considerable damage is said to have occurred in the early days of electric traction in England, although such damage was apparently insignificant compared to conditions familiar in America. Practically no damage has occurred in recent years, and certainly no extensive damage. Two or three cases, local in character and of small extent, have occurred in localities where the Board of Trade regulations were complied with.

In England there is very little good evidence in the way of tests, and the general statements of immunity are based on the absence of trouble. The Post Office and the South Metropolitan Gas Company (London) both make systematic tests and find no trouble, with the exception that the Post Office has from time to time encountered difficulties due to stray currents, which were however generally quite local in character.

While it is generally stated in England that there is little actual damage to piping systems, and that the problem is not an important issue with the owners of gas piping systems, there is considerable feeling among the privately owned gas companies that they are not adequately protected by the Board of Trade Regulations, since they cannot recover damages in case corrosion occurs where the Regulations are complied with. This has led to numerous applications to Parliament for special clauses in Acts granting powers to electric railway undertakings; most of these have been refused, but some have been granted.

It is generally admitted that the Board of Trade Regulations, as originally drawn, were empirical, and that they might be remodelled with advantage, but since the only feature of the regulations actually rigidly enforced: namely, the limit for overall rail drop, results in substantial immunity, the great difficulty attending revision does not seem justified.

83. Protective Measures in Vogue.

Feeders.

Germany. Insulated return feeders are used almost universally in Germany. In Berlin and Hamburg these return feeders are of the same number and size as the positive feeders, but generally in other towns the return feeders are of smaller cross-section. Separate feeders are generally used, but not exclusively, as feeders with resistance taps are used in some cases. Formerly there were cases of feeders tapping at several points, but important cases have been corrected by the insertion of resistances. (The distinction between copper which merely parallels the rails, and feeders intended to maintain equi-potential points in the rail net-work, is clearly understood in Germany).

Negative boosters are used in several cases, but the general practice is not to use them. The tramway in Danzig, operated by a private company, and having a maximum load of 600 kw., has used boosters since 1906.

Return feeder systems are carefully calculated in recent installations; the same grade of insulation is generally provided for both positive and negative feeders. No design data for feeder resistances were obtained.

England. Insulated return feeders are used in England, wherever return feeders are necessary to bring the rail drop within the B.O.T. regulations Separate feeders are generally used. (As in Germany, the feeders are intended to maintain the rail taps at the same potential throughout the system).

Negative boosters are more extensively used than in Germany. They are very commonly used in the larger systems, although in one large city their use was abandoned after they had been in operation for some time. They are considered more economical than resistances in the return feeders, and also to provide better regulation where the load centers shift.

Return feeder systems are only calculated in the larger,well supervised systems, elsewhere they are installed on "cut-and-try" methods. The same grade of insulation is usually provided for both positive and negative feeders.

Italy. Return feeders are not used for tramways in Italy.

France. Insulated return feeders are used for the conduit tramways in Paris, but little elsewhere. Most systems have but one feeding point to the rails. Boosters are very little used, the only system found to be equipped with boosters was that of the Cie. des Tramways de Paris et du Dept. de la Seine.

Voltage and Current Conditions.

Germany. Where return circuits have not been remodelled in accordance with the Commission Regulations, overall voltage limits vary greatly, but in the majority of cases they are between 5 and 10 volts. Other systems will be from 2 to 5 volts. Negative feeders are designed for equal drop.

England. Overall rail drops for tramways in England are generally very much lower than the B.O.T. requirement, averag ing probably 2.5 to 3 volts, with the exception of occasional drops, which may be as high as 15 or 20 volts, due to extraordinary traffic at foot-ball matches, etc. The railways probably have higher overall voltages than the tramways. Glasgow, which voluntarily adopted a 2 volt rail drop limit, Manchester, and other large towns, have extraordinarily low rail drops. Electrolysis conditions throughout the United Kingdom are generally said to be satisfactory, although some private gas companies do not agree to this. Potential differences between pipes and rails are said to be generally less than 1 volt.

Negative feeders are designed for equal drop.

France. It is stated that the tramways in France generally endeavor to observe the 1 volt per km. limit. Potential differences between pipes and rails rarely exceed 1 volt (However we observed a 6 volt potential in Paris).

Miscellaneous Protective Measures.

Drainage System. Electrical drainage was formerly applied in one or two cases in Germany, notably in Aachen, but it was abandoned on account of damage produced by it, first, due to joint corrosion, and second, damage to other underground structures. It is condemned by the engineers of the Earth Current Commission.

Electrical drainage is not employed in Italy or France.

In England, it is not approved as a general measure to afford relief from stray current, although there are a few special instances of its application to the Railway Company's own lead covered cables, where the common practice is to bond to the rails at many points. One engineer thought that it might be applied where currents were small, except to gas pipes on account of the danger from sparking, he also thought that it would be undesirable in America where large currents are carried.

Negative Trolley or Periodic Reversal. The trolley wire was originally made negative in Nürnberg, and in St. Gall, Switzerland, but not periodically reversed. The scheme has been abandoned in both places.

This connection has not been used for tramways in Italy, France or England.

Three-Wire System. The three wire system has been applied to electric railways in a few cases in Germany. In each case the distribution of load between polarities was by districts, that is, certain entire sections will have the trolley wire positive, and others will have the trolley wire negative. Under these conditions the systems may become considerably unbalanced.

In France, the Nord-Sud Chemin de Fer employs a three-wire system with two motors per car, positive and negative, the running rails acting as a grounded neutral.

In England the three-wire system has not been applied to tramways. The City and South London Underground Railway employs it, but this will be discontinued following consolidation with other systems.

Average Feeding Distances. In England, the average feeding distances are said to be from 2 to 3 miles.

Joints in Cast-Iron Mains. Cast-iron pipes in England and Germany are generally of the lead calked bell and spigot type. In Germany flanged joints are frequently used for special fittings, valves, T's and hydrant taps for water mains. Cast-iron pipes are little used in France; pipe joints are either lead calked bell and spigot, or in large pipes flanged with rubber gaskets. Insulating joints are not used, except that in England it is said that they are occasionally used for water pipes in very special cases.

Insulating Coverings. In Germany it is held that insulating coverings do not afford protection against electrolysis, as their effect is merely to concentrate escaping stray currents, since perfect coverings cannot be maintained. They should only be used where protection against chemical corrosion is desired, due to the character of the soil.

In France, gas engineers stated that insulating coverings were being studied, but it was not believed that they would prove practicable.

In England, insulating coverings are not considered good protection against stray railway currents. High pressure gas pipes have been covered with pitch canvas, and the London Water Board pipes are provided with an asphalt dip coating, but more as protection against chemical corrosion.

Insulating Joints in Telephone Cables. Not used in Germany or England.

Double Trolley. The double trolley system is not in general use in any of the countries visited. One or two very special cases near Laboratories in Germany, the district within 2 or 3 miles of the Greenwich Observatory, and some conduit tramways of the London County Council System, were the only cases noted. The double trolley is also used in connection with a few miles of rail-less trolley in England.

Corrosive Effects of Soil. In Germany the possibility of chemical corrosion (that is, corrosion without an external supply of electricity) is recognized, and distinction is made between such corrosion and that produced by stray currents. Pipe corrosion has actually been found under conditions where it could not have been produced by stray currents. The resistance of soil is said to vary from 1 ohm to 2000 ohms per cubic meter, averaging about 100 ohms per cubic meter.

No definite information was obtained in England regarding the corrosive properties of soil, but it was stated that chemical corrosion was known to occur. Such corrosion does not, however, produce acute conditions, as in electrolysis; it is more like ordinary oxidation.

Effect of Roadbed Construction on Leakage Current. The authorities consulted in Germany were of the opinion that the road-bed constructions used did not effect a reduction of leakage from the tracks. A similar opinion was held in England. (See Fig. 10-13).

Rail-Weights. In Germany the common rail weights are 50-60 Kg. per meter for tramways, and 30-40 Kg. per meter for interurban lines. In France the ordinary rail-weights are 46 to 51 Kg. per meter. In England rail-weights vary from 70 to 100 lbs. per yard, in the majority of cases. (See Fig. 14).

Welded Rail-Joints. In Germany Thermit welds are used to some extent, they are becoming more common. In France the rails of the System Cie. de Omnibus Thomson-Houston, are welded.

In England Thermit welds have been very extensively used, giving good results electrically, but having short life due to mechanical weakness where traffic is heavy. A type of electrically welded continuous rail, very extensively used in Leeds, and to an increasing extent in Manchester and Glasgow, is giving excellent results, being mechanically strong and providing good electrical conductivity.

Rail-bonds. Solid copper pin type bonds, usually 1 meter long, are most commonly used in Germany, and also in France. The Metropolitan System in Paris places the bonds under the base flange of the rail.

In England, solid copper pin type bonds, protected bonds inside of fish plates, and other types familiar in America, are generally used. (See Fig. 15).

Cross-bonds. In Germany, cross-bonds are used about every 10 rails, *i.e.*, every 100 meters. In France, cross-bonds are placed every 50-100 meters, they have the same area as the rail-bonds. In England cross-bonds are placed generally every 40 yards, they have the same area as the rail-bonds. (See Fig. 16).

Depth of Pipes etc. Below Surface. In Germany, gas pipes are generally laid 0.8-1. meter, and water pipes 1-1.5 meters, below the surface. In France, gas pipes are laid where possible 0.6 meter below the surface, L.T. cables 0.7 meter, and H.T. cables 1.3 meters. In England 1 foot is said to be dangerous; 2 feet was given by one authority as an average and 2.5 to 5 feet by another. In all cases the above depths are only typical, the practice varies widely.

Mains on Both Sides of Streets. In Germany, France and England, mains are laid on both sides of principal streets, or streets wider than 14 meters (Paris) or in streets with wood or asphalt pavements, and generally in the larger towns. In narrow streets or in unimportant places, one main is used.

84. Economic Aspects of the Electrolysis Problem. About 40 per cent of the electric railway systems in Germany, and about 70 per cent in England, are municipally owned. In Germany one authority thought that municipalities were more ready than private companies to spend money for the purpose of improving their return circuits, but in England it was thought that there was no difference in this respect.

Opinions differed in Germany as to whether or not the prevailing regulations constituted a financial hardship. In England, the Board of Trade regulations are nowhere considered a hardship, and when inquiry was made as to whether the existing regulations had retarded the development of electric railways, the authorities consulted uniformly stated that this was not the case. It appears that in fact a saturation point has been reached, and busses are being used where tramways would not pay. Traffic conditions are said to be quite as heavy in England as in the United States. Only one authority in England ventured an estimate of the average load factor for English electric railway systems, he estimated it to be 35 per cent.

There is very little overhead feeder line construction in Germany, and almost none in England.

85. Regulations and Tests. The German Earth Current Commission Regulations only attain the force of law when incorporated in the contracts between civil authorities and the railroad companies, or, as in the case of many cities, where it is provided that new work be done in accordance with "existing technical standards." The Commission regulations are being generally incorporated in contracts for new enterprises or extensions. Also, other undertakings not subject to its provisions are changing over voluntarily for reasons of policy or economy, or as the result of compromise to avoid litigation; this is said to be the case in 30 or 40 important towns.

So far as could be ascertained, no local ordinances exist in Germany regarding electrolysis. In England, there are no local ordinances which have the effect of modifying the Board of Trade regulations. Certain gas companies have obtained special statutory orders, fixing the responsibility for damage, but these do not modify the Board of Trade regulations.

In applying the Earth Current Commission Regulations in Germany, the term "average schedule traffic" is interpreted to mean the average for the entire period of operation which is usually 18 or 19 hours per day. If the measurements are not actually taken over the entire period, they are corrected to obtain a figure corresponding to this average.

In England, measurements are based on an average for about 20 minutes at peak load. The "average" is obtained as the mean between the average of the maxima during this period, disregarding unusually high swings, and the actual average of all measurements. This quantity is usually obtained in practice from inspection of recording instrument charts.

The British Board of Trade makes inspections on its own initiative, because it is responsible for its rules, which have substantially the force of law; they also investigate complaints. There are no regular inspections, on account of the lack of a proper appropriation; most of its information is obtained by means of circular returns, provided for in the Regulations. The latest call for a return was issued in 1906.

In Germany, permanent means for measuring overall potentials are very generally provided, but the methods of doing this vary widely. Pilot wires are usually provided for new installations in France.

In England, pilot wires are universally used in connection with recording instruments. The practice varies widely, but the most common method employs 14 or 16 gauge wires laid with the main cables, and extended beyond them.

Bond testing is generally done in Germany on some systematic basis, more often annually, but in some large systems semi-annually. The bond testing devices are generally of the three contact type with differential galvanometer. Some of these are said to be undesirable on account of the form of the contact, others because the rail joint points span too short a length, or on account of the type of galvanometer employed, etc. In England, it is stated that there is practically no systematic bond testing except in the large, well supervised systems.

I. GENERAL REMARKS.

86. Germany. Where municipalities own the water, gas and street railway systems, they may prefer to assume the cost of damage rather than making larger expenditure for protection of their pipes. There are cases in dispute pending in Essen and Aachen. In Aachen the drainage system was formerly used, but gave trouble; changes are under study or under way.

Recently the case of Mansfeld was decided against the gas company as the railway existed before the gas plant.

Hamburg, prior to the forming of the commission, installed return insulated feeders which gave valuable information in guiding the recommendations of the commission.

Strassburg found in summer 50 % greater leakage than in winter when measurements were made in cold weather and the ground frozen. In snow storms, however, the leakage was increased as the cars were using more current.

The Prussian Law protects railway companies against suits for damages caused by stray currents whenever the pipe owning concerns did not apply for protection against these possible damages before the original franchise to the Railway Company was granted.

Similar laws apply in other States.

When the municipality assumes the operation of a railway it does not assume responsibility to protect the pipe owning companies against damages due to stray currents.

87. France. In Paris pipes for water are located in sewers and therefore remote from trouble.

Telephone cable troubles are few in Paris. In the suburbs all underground pipe systems are more or less affected.

Twenty suits are now in litigation between the gas companies and the railways.

J. STATISTICAL—OPERATING—STRUCTURAL AND TECHNICAL DATA.

TABLE 1.

88. Magnitude of Electric Railway Undertakings in German Empire and United Kingdom.

	German Empire 1911	United Kingdom 1912
Number of undertakings	258	262
Miles of single track	4,920	4,202
No. of cars of all kinds	26,078	12,860
Capital expended £	54,354,625	77,087,944
Car miles	430,512,031	326,688,674
No. of passengers	2,631,892,678	3,145,805,137
Gross income £	13,237,024	14,593,052

TABLE 2.

89. Tramways not Operated by Electricity.

	Miles of single track.			
	Horse	Steam locomotive	Cable	Petrol motors, etc.
German Empire, 1911	45.1	49.8	4.1	10.0
United Kingdom.1912	38.7	42.3	50.1	4.8

TABLE 3.

90. Ownership of Electric Railway Undertakings

A—German Empire, 1911.

	Private corporations	Local authorities	Public ownership operated by private corporations
No. of undertakings	112	110	36
Miles of single track	2,711	1,646	563
No. of cars of all kinds	16,390	7,756	1,932
Capital expended £	32,685,120	16,232,025	5,437,480
Car miles	260,729,075	134,466,975	35,315,981
No. of passengers	1,519,571,662	899,127,262	213,193,754
Gross income £	8,095,757	4,118,873	1,022,394

B—United Kingdom, 1912.

	Private corporations	Local authorities
No. of undertakings	94	168
Miles of single track	1,115	3,078
No. of cars of all kinds	3,444	9,416
Capital expended £	22,648,596	54,439,318
Car miles	81,191,368	245,497,306
No. of passengers	621,546,806	2,524,358,331
Gross income £	3,534,873	11,058,179

TABLE 4.

91. Statistics of Tramways in Large Cities.

A—German Empire.

	Max. load kw.		Avg. car miles per diem		Avg. pass. per diem		Annual gross Income-marks	
	Actual	Per 10,000 Popul.	Actual	Per 10,000 Popul.	Actual	Per 10,000 Popul.	Actual	Per capita.
Hamburg (935,000)	..	..	91,450	981	460,000	4940	12,208,781	12.97
Leipzig (590,000)	2,145	36.5	59,910	1020	328,500	6590	11,129,573	18.95
Dresden (550,000)	3,300	60.3	59,410	1085	345,800	6320	12,324,054	22.55
Dusseldorf (360,000)	1,386	38.8	27,040	756	183,000	5120	5,524,714	15.45
Nürnberg (330,000)	880	26.5	18,860	569	108,600	3280	3,543,810	10.69
AVERAGE........	..	40.5	....	882	..	5050	....	M16.12 $ 3.85

B—United Kingdom.

	Max. load kw.		Avg. car miles per diem		Avg. pass. per diem		Annual gross Income-pounds	
	Actual	Per 10,000 Popul.	Actual	Per 10,000 Popul.	Actual	Per 10,000 Popul.	Actual	Per capita.
Manchester 1,250,000)	11,000	88	51,400	411	510,400	4082	887,647	0.710
Glasgow (1,150,000)	11,500	100.	63,950	556	854,000	7422	1,070,175	0.932
Birmingham (900,000)	..	..	36,000	400	368,000	4088	581,566	0.646
Leeds (450,000)	4,500	100.	24,100	536	245,800	5460	411,531	0.914
Dublin (390,000)	4,500	115.4	19,650	504	147,700	3790	293,748	0.752
AVERAGE.......	..	100.9	....	481	....	4968	....	£ 0.791 $ 3.84

TABLE 5.

92. Statistics of Tramways in Small Cities.

A—German Empire.

	Max. load kw.		Avg. car miles per diem		Avg. pass. per diem		Annual gross Income-marks	
	Actual	Per 10,000 Popul.	Actual	Per 10,000 Popul.	Actual	Per 10,000 Popul.	Actual	Per capita.
Cassel (153,078)	469	30.6	6215	406	38,550	2516	1,474,199	9.62
Braunschweig (143,534)	466	32.5	7090	494	33,100	2306	1,205,577	8.40
Erfurt (111,461)	304	27.3	3580	321	19,010	1708	637,792	5.72
Freiburg (83,328)	165	19.8	2742	329	18,860	2264	664,625	7.98
Solingen (50,540)	250	49.5	3730	738	23,250	4600	973,240	19.25
AVERAGE........	..	32.0	....	458	....	2679	....	M10.20 $ 2.15

B—United Kingdom.

	Max. load kw.		Avg. car miles per diem		Avg. pass. per diem		Annual gross Income-pounds	
	Actual	Per 10,000 Popul.	Actual	Per 10,000 Popul.	Actual	Per 10,000 Popul.	Actual	Per capita.
Brighton H. (173,000)	995	57.5	3165	183	31,000	1792	53,748	0.311
Dundee (168,600)	1700	101.0	3725	221	48,550	2880	65,045	0.386
Preston (121,000)	600	49.6	2660	220	26,200	2166	43,270	0.358
Coventry (91,000)	750	77.0	2720	299	20,900	2297	39,153	0.430
Burton T. (50,000)	375	74.4	1240	246	9140	1815	16,897	0.316
AVERAGE........	..	72.0	....	234	....	2190	....	£ 0.360 $ 1.75

TABLE 6.

93. Rail Bonding.
United Kingdom.

	No. of undertakings	Miles of single track	Per cent of total (miles)
Copper Bonds.			
Solid copper, type not specified	46	560.	....
Flexible " " " "	9	176.	....
Crown—3/0 and 4/0	20	321.	....
Neptune 4/0	19	229.2	....
Chicago	8	71.3	....
Forest City	5	37.2	....
Misc. and type not specified	15	406.8	....
TOTAL, copper bonds only	122	1801.5	47.3%
Welded Rails, Etc.			
Continuous rails, type not specified	1	17.	....
Yalk cast weld	1	20.	....
Thermit	3	61.6	....
" and Yalk	1	15.9	....
" and Tudor	1	28.	....
" and Oxy-Acetylene	1	18.	....
TOTAL, entirely welded	8	160.5	4.2%
Partially Welded:			
Copper and Thermit	31	1312.4	....
" " other welded joints	5	377.3	
TOTAL, partially welded	36	1689.7	44.3%
Plastic Bonds, Etc.			
Plastic bonds and copper	3	147.5	....
" " " Thermit	1	12.3	....
	4	159.8	4.2%

TABLE 7.
94. Use of Negative Boosters. United Kingdom.

	Number	Miles of single track
Total number of undertakings	183	3835.
Number of undertakings using negative boosters	39	1152.
Per cent using negative boosters	21.3%	30. %

Relation between Booster Capacity and Plant Capacity

Average, for 25 cases: Booster Capacity—3.9% of plant capacity.

Highest— 9 % for plant of 500 kw. capacity
12 % " " " 800 " "
Lowest —0.8 % " " " 5725 " "
0 9 % " " " 3500 " "

TABLE 8.
95. Distribution Systems for Tramway Feeders. United Kingdom.

	No. of undertakings	Miles of single track
Solid system, all types	80	1888.2
Conduit " "	63	1839.2
Solid and conduit	21	626.1
Overhead, wholly or partly	6	40.9
	170	4394 9
Not reported	11	
	181	

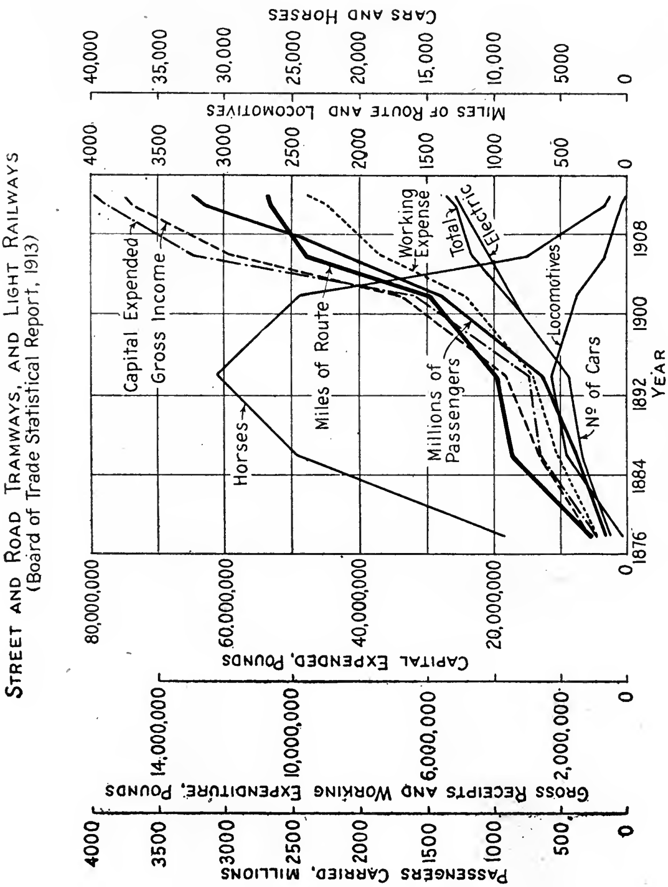

Street and Road Tramways, and Light Railways
(Board of Trade Statistical Report, 1913)
Cars and Horses
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
Miles of Route and Locomotives
4000
3500
3000
2500
2000
1500
1000
500
0
Capital Expended, Pounds
80,000,000
60,000,000
40,000,000
20,000,000
0
Gross Receipts and Working Expenditure, Pounds
14,000,000
10,000,000
6,000,000
2,000,000
0
Passengers Carried, Millions
4000
3500
3000
2500
2000
1500
1000
500
0
1876
1884
1892
1900
1908
Year
Capital Expended
Gross Income
Horses
Miles of Route
Millions of Passengers
Working Expense
Total
Electric
Locomotives
Nº of Cars

Figure 9

TRACK CONSTRUCTION - UNITED KINGDOM

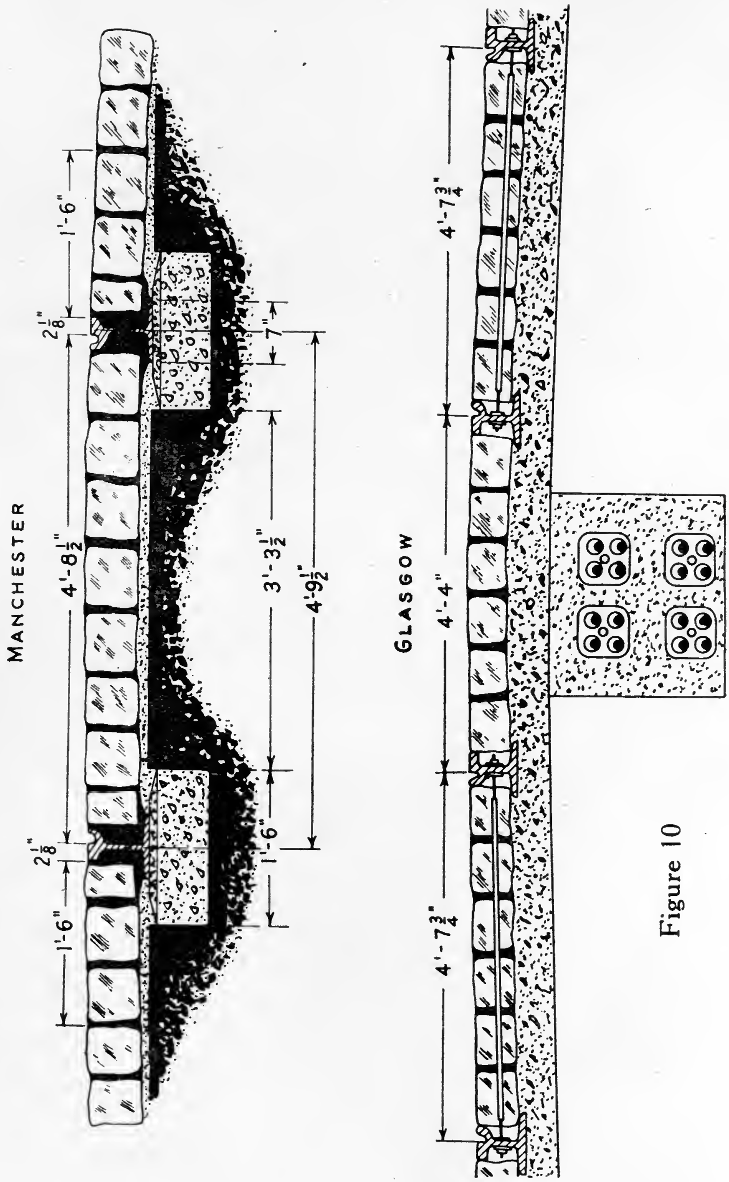
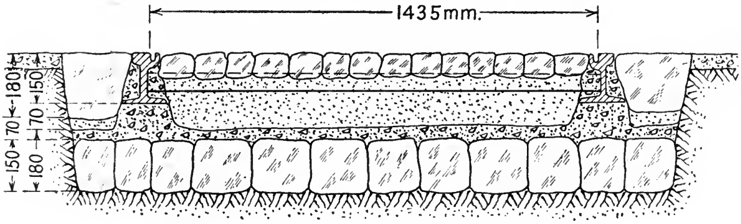


Figure 10

Track Construction and Rails - Germany



Typical Construction for paved street

Strassburg
Haarman 3 piece Rail, and foot plate

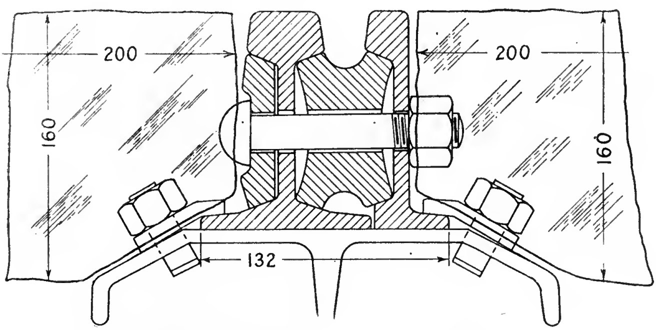


Figure 11

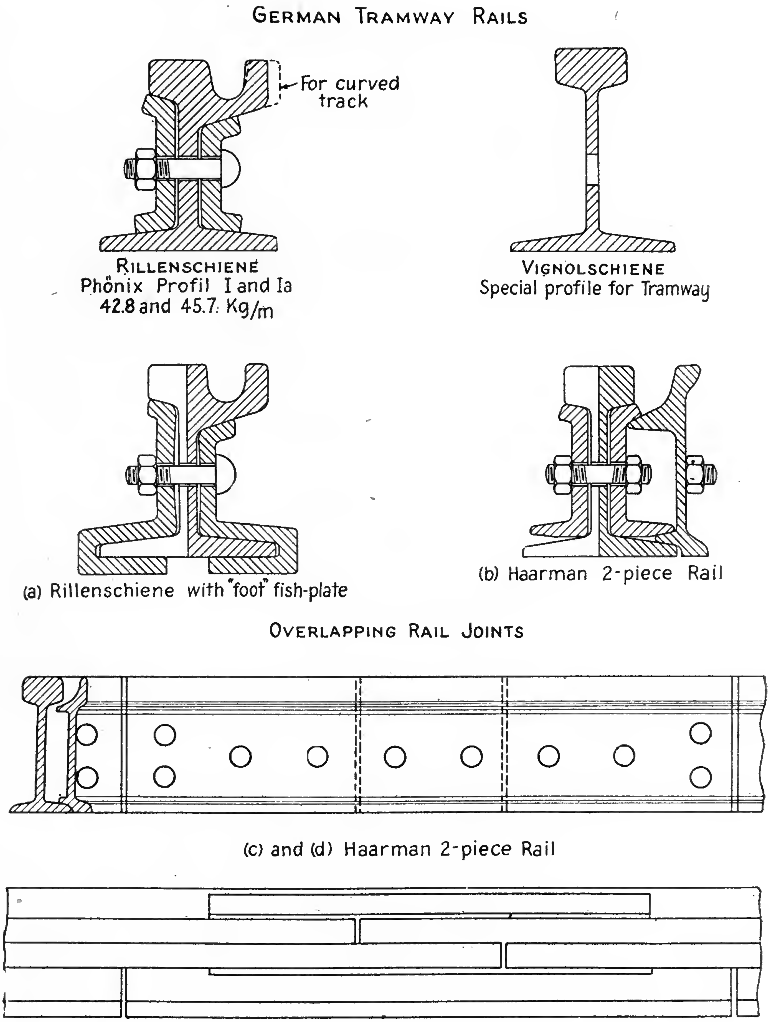

German Tramway Rails
For curved track
Rillenschiene
Phönix Profil I and Ia
42.8 and 45.7 Kg/m
Vignolschiene
Special profile for Tramway
(a) Rillenschiene with "foot" fish-plate
(b) Haarman 2-piece Rail
Overlapping Rail Joints
(c) and (d) Haarman 2-piece Rail

Figure 12

BRITISH TRAMWAY RAILS

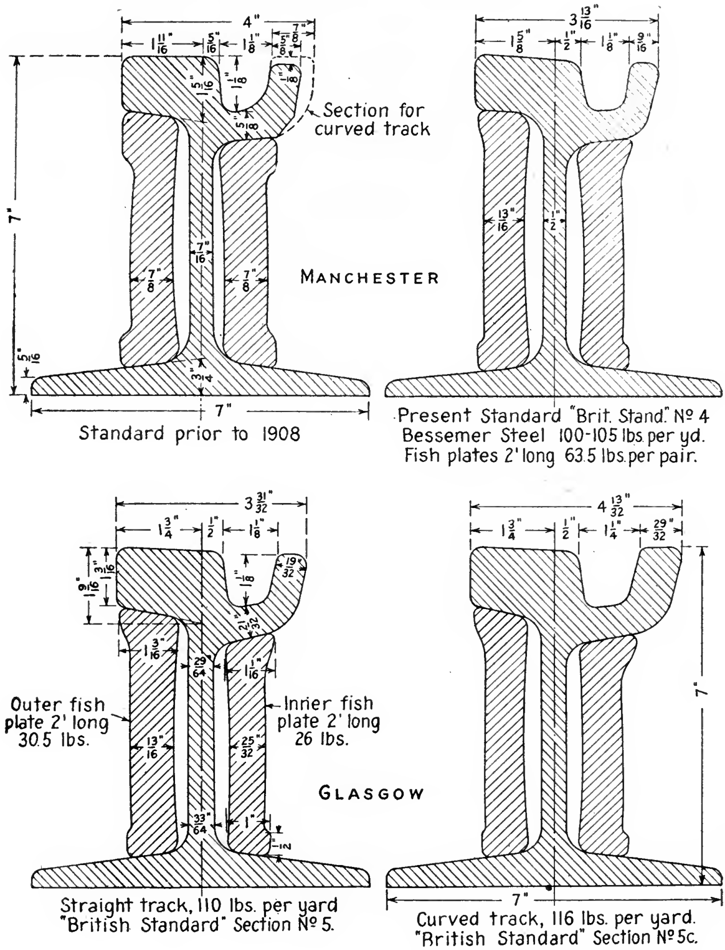


Figure 13

RAIL WEIGHT DATA

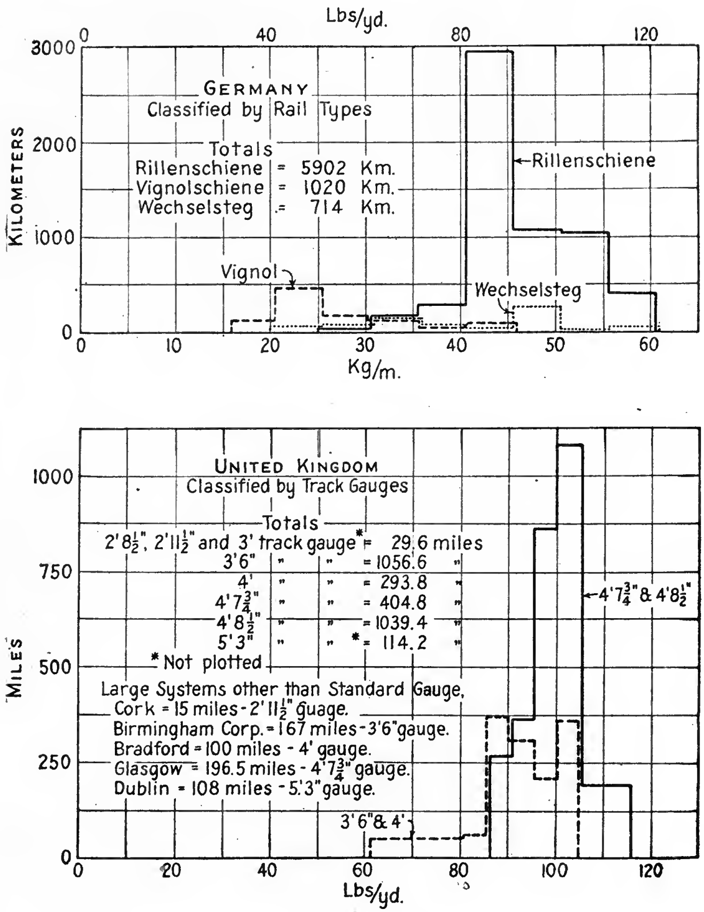


Figure 14

Typical Rail Bonds - United Kingdom

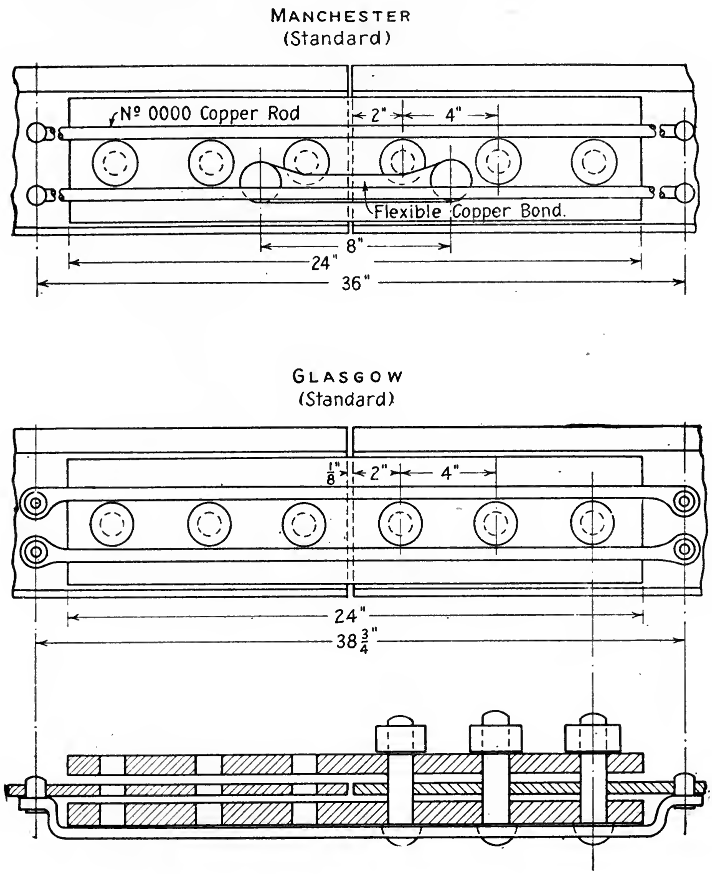
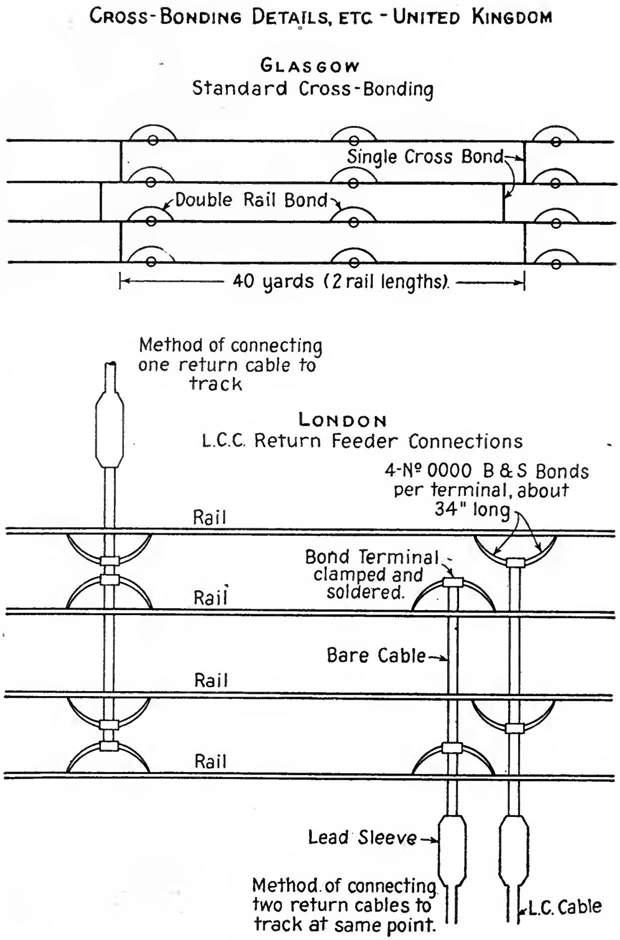


Figure 15



Cross-Bonding Details, etc - United Kingdom
Glasgow
Standard Cross-Bonding
Single Cross Bond
Double Rail Bond
40 yards (2 rail lengths).
Method of connecting one return cable to track
London
L.C.C. Return Feeder Connections
4-Nº 0000 B & S Bonds per terminal, about 34" long
Rail
Rail
Rail
Rail
Bond Terminal clamped and soldered.
Bare Cable
Lead Sleeve
Method of connecting two return cables to track at same point.
L.C. Cable

Figure 16

96. Electrolysis Testing Methods. The surveys made by the engineers of the Earth Current Commission of Germany are systematically planned. They start with a general investigation of geological conditions, the character of the soil, ground water, and so forth, continuing with a general survey of the present condition of the railway property, including distribution of load, track and rail resistance, location and loading of supply and return circuit cables, and any other electrical data relating to the investigation. The surveys then take up the specific measurements relating to stray current, such as potential differences between pipes and rails, current in pipes, and so forth. The surveys conclude generally with recommendations for betterments where such are needed, and often include estimates of the cost of such improvements.

In England very little testing is done to investigate electrolysis questions and no technique has been developed for such work. The only extensive work in recent years is that of the Cunliffe brothers, and their work was directed mainly toward the investigation of certain theoretical questions rather than toward the systematic investigation of any railway system. The work of the Cunliffes appears in two papers presented by them before the British Institution of Electrical Engineers.

97. Abstract of Laws and Regulations or Recognized Standards in European Countries.

(See next page.)

Country	England	France	Germany	Italy	Spain.
Nature of Regulations,	Board of Trade Regulations. Original issue March 1894, last revision Sept. 1912.	Ministerial Decree of Mar. 21, 1911.	No laws, but the Recommendations of the German Earth Current Commission are recognized as Standards.	No laws or Municipal Regulations	Law of Mar. 23, 1900.
Maximum Rail Drop, (See text as to how determined in different countries)	7 volts total.	1 volt per km.	2.5 volts total in central district; 1.0 volt per km. in outer districts.		7 volts total.
Return Feeders,	May be uninsulated unless drop exceeds 7 volts.	Must be insulated.	Must be insulated.		
Rail Bonds: Tested,		Periodically and record kept.	Yearly		
Resistance not to exceed		10 meters of rail	10 meters of rail		Section must exceed 100 sq. mm. per rail.
Connections to pipes,	For test purposes may connect to water mains of 3 in. or more diameter with owner's permission.		Prohibited.		
Pilot wires,		Must be provided.	To be provided.		

L. MISCELLANEOUS NOTES.

98. Plan of German Earth Current Commission Reports. In abstracting these reports we have selected at random characteristic studies which would illustrate the method pursued in the investigations. We have not made any attempt at all to select studies for direct comparison with any specific American condition. In interpreting these results, the above qualifications should, therefore, be kept in mind.

The reports are quite uniform in character and contain in general the following data:

I. Maps showing the location and extent of the tramway, water pipe and gas pipe systems, location of the generating station or stations, points of connection of the supply and return feeders.

II. Soil—kind (clay, sand, loam, etc.) moisture content, chemical composition, resistance per cubic meter.

III. Pavements—(in some cases only).

IV. Piping systems—both water and gas pipes. Total length, diameter, material, age, depth below surface, kind of joints, resistance of pipe only and of pipe including joints.

V. Tramway system.

(a) General details of ownership and operation, car schedule, maximum and average loads.

(b) Track and rails—total miles of single and double tracks, gauge, rail profile and cross section, standard length, resistance of rail alone and including bonds.

(c) Rail bonds and cross bonds, type, cross section, per cent increase in rail resistance caused by bonds.

(d) Feeders, both supply and return feeders—length each, cross section, total weight of copper, current—maximum and average, return feeders bare or insulated and with or without regulating resistance.

VI. Tests.

(a) Voltage between pipes and rails, maximum, minimum and average, with polarity, determined at numerous points on the system.

(b) Voltage drop per kilometer on pipes and on rails, and calculated current flowing on pipes.

(c) Determination by means of telephone wires of the relative potential of various points on the piping and on the rail systems.

VII. Excavations in likely places to determine the existence and extent of the electrolytic damage.

VIII. Plates accompany the reports, giving graphically many of the above data, frequently on transparent paper so that when placed over the city map the details of streets, railroads, etc. can be observed.

Reasoning from the data contained in the body of the report, recommendations are made for improving conditions, sometimes accompanied by an estimate of cost. In some cases a supplementary report is made which shows the conditions after the changes recommended had been made, in whole or in part.

99. General Comments on Reports. The electrolysis troubles in all cases were confined to a few localities, and in no case was the yearly cost of repairs of such amount that, on the surface, would justify large expenditure of money for improvements. The Commission, however, while recognizing the importance of the financial aspect of the problem, still recommended the adoption of the relatively expensive remedies for the reason they state "that the repairs will certainly become more frequent with lapse of time, and besides the increased expense so caused, there is the liability of service interruption, disturbance of traffic, pavement replacement and even danger of explosion to be considered."

V. BIBLIOGRAPHY

This committee has made a complete search of the American literature on the subject of electrolysis, but in compiling the following bibliography no attempt has been made to list this literature in its entirety. This bibliography may be considered a selected list of such contributions to the subject known to the committee, as, in its opinion, are of permanent value.

Bureau of Standards Publications: The following Technologic Papers upon electrolysis have been published by the Bureau of Standards at Washington, D. C.

No. 15. Surface Insulation of Pipes as a Means of Preventing Electrolysis.

No. 18. Electrolysis in Concrete.

No. 25. Electrolytic Corrosion of Iron in Soils.

No. 26. Earth Resistance and its Relation to Electrolysis of Underground Structures.

No. 27. Special Studies in Electrolysis Mitigation.

No. 28. Methods of Making Electrolysis Surveys.

No. 32. Special Studies in Electrolysis Mitigation, No. 2, Electrolysis from Electric Railway Currents and its Prevention—Experimental Test on a System of Insulated Negative Feeders in St. Louis.

No. 52. Electrolysis and Its Mitigation.

No. 54. Special Studies in Electrolysis Mitigation, No. 3. A Report on Conditions in Springfield, Ohio, with Insulated Feeder System Installed.

No. 55. Special Studies in Electrolysis Mitigation in Elyria, Ohio, with Recommendations for Mitigation.

No. 62. Modern Practice in the Construction and Maintenance of Rail Joints and Bonds in Electric Railways.

No. 63. Leakage of Current from Electric Railways.

No. 72. Influence of Frequency of Alternating or Infrequently Reversed Current on Electrolytic Corrosion.

No. 75. Data on Track Leakage.

Deiser, George F. "The Law Relating to Conflicting Uses of Electricity and Electrolysis," T. & J. W. Johnson Co., Philadelphia, Pa., 1911.

Farnham, Isiah H. "Destructive Effect of Electric Currents on Subterranean Metal Pipes," *Trans.* A. I. E. E., 1894.

This paper probably covers the first investigation undertaken of real scientific value. The discussion of the paper is also important and interesting.

"Means for Preventing Electrolysis of Buried Metal Pipes," *Cassiers Magazine*, August, 1895.

This article is of particular interest, in that it shows that at a very early date the value of the insulated negative feeder system as a means of mitigating electrolysis was recognized.

Ganz, Albert F. "Electrolytic Corrosion of Iron by Direct Current in Street Soils," *Trans.* A. I. E. E., Vol. XXXI, p. 1167, 1912.

This paper gives the results of a laboratory investigation of considerable scientific value and interest.

"Electrolysis from Stray Electric Currents," *Proc. New England Association of Gas Engineers*, 1913.

This paper treats the subject in a popular, but nevertheless scientifically correct manner, and leads to the conclusion that the insulated negative feeder system is the logical one to employ for the purpose of mitigating electrolysis.

"Effects of Electrolysis on Engineering Structures," Trans. Inter. Eng. Congress, San Francisco, Cal., 1915.

This paper gives a review of electrolysis conditions and of mitigating methods in America with a brief statement of the electrolysis situation in Europe.

Haber, F., and Goldschmidt, F. "Der Anodische Angriff des Eisens Durch Vagabundierende Strome im Erdreich und die Passivitat des Eisens." (The Corrosion of Iron by Stray Currents in the Ground and the Passivity of Iron.) *Zeitschrift fur Electrochemie*, January 26, 1906. Breslau.

A paper of considerable scientific value, particularly with respect to the electrochemistry of the subject. In so far as is known no English translation exists.

Harper, Robert B. "Comparative Values of Various Coatings and Coverings for the Prevention of Soil and Electrolytic

Corrosion of Iron Pipe," *Proc. Illinois Gas Association*, Vol. 5, 1909.

A paper based upon a rather elaborate series of tests carried out in a thoroughly scientific manner on many coatings and coverings, leading to the conclusion that no coatings or coverings are of permanent value in positive areas. Of all coatings investigated, dips of coal tar pitch applied hot, were found to be best. Paints were found to be practically useless.

Hayden, J. L. R. "Alternating-Current Electrolysis," *Trans.* A. I. E. E., 1907. Vol. 26, Part I.

A report of a laboratory investigation tending to show that alternating current electrolysis is small as compared with direct current electrolysis. The tests also bring out the inhibiting effect of the superposition of a small direct current.

Jackson, Dugald C. "Corrosion of Iron Pipes by Action of Electric Railway Currents." *Journal of Association of Engineering Societies*, September, 1894.

An account of some early laboratory investigations carried out at the University of Wisconsin, in which it was definitely proven that corrosion due to electrolysis could take place at very low voltages—considerably lower voltages than are required to decompose water.

Michalke, Carl. "Stray Currents from Electric Railways." Translated and edited by Otis Allen Kenyon, McGraw Publishing Company, New York City, 1906.

A relatively non-mathematical, though scientific and valuable treatment of the subject.

Rhodes, George I. "Some Theoretical Notes on the Reduction of Earth Currents from Electric Railway Systems, by Means of Negative Feeders." *Trans.* A. I. E. E., Vol. XXVI, p. 247, 1907.

A mathematical paper showing quantitatively the difference in effectiveness of copper paralleling the rails and insulated negative feeders in reducing stray currents.

Schaffer, Guy F. "Corrosion of Iron Embedded in Concrete." *Engineering Record*, July 30, 1910.

This is a report of a series of tests made at the Massachusetts

Institute of Technology, carried out with the view of obtaining some data on the effect of currents of low potential on steel embedded in concrete. The study included the effect on steel in both the stressed and unstressed condition, also the effect of setting cement on paint films. It was shown (a), that concrete does not act as an insulator; (b), that iron under stress does not go into solution as rapidly as unstressed iron; and (c), that the paints used to-day for structural work embedded in concrete do not fulfill the conditions of proper protection from electrolytic action, and it is doubtful whether they are of use for protection in any sense after a lapse of some months.

Sever, George F. "Electrolysis of Underground Conductors." *Trans. International Electrical Congress*, St. Louis, Vol. 3, p. 666, 1904.

This is a summary in tabular form, consisting of street railway practice, municipal reports, ordinances and letters in force in the United States at the time the report was prepared, 1904. The discussion which followed the presentation of this report is of interest.

Stone, Charles A. and Howard C. Forbes. "Electrolysis of Water Pipes." *New England Water Works Association*, Vol. 9, 1894-95.

This is the report of the results of an investigation of electrolysis conditions in Boston. It is one of the best early papers on the subject. The discussion of this paper is interesting.

Topical Discussion on Electrolysis. *Proc. New England Water Works Association*, Vol. XX, 1905.

This is the report of a discussion entered into by various New England Water Works superintendents. Several phases of the discussion are instructive.

VI. APPENDICES.

100. Resistance of Standard Cast Iron Pipe.

Note: The values given in this table are for one assumed specific resistance for cast iron, wrought iron and steel, respectively. For exceedingly accurate work, measures should be taken to determine the actual specific resistance of the metal under test. Experience has shown that this may vary widely from that assumed in the tables; in other words, the table values can only be used for approximate results unless definite information is at hand as to the specific resistance of the metal under test.

From pages 379 and 386, 1913, *Proceedings American Electric Railway Engineering Association.*

TABLE FOR DETERMINATION OF CURRENT FLOW ON PIPING FROM MILLI-VOLT DROP ALONG CONTINUOUS LENGTH OF PIPE BETWEEN JOINTS.

L = Distance between contacts in feet
E = Instrument reading in milli-volts,
K = Constant from table.

$$\frac{KE}{L} = \text{Current flow in amperes.}$$

TABLE 9

STANDARD CAST IRON PIPE.

(Based on a resistance of 0.00144 ohm per lb. ft.)

Classification					Actual Dimensions			
Nominal. Dia.in.	*Association Standard	Class Letter†	Head Feet	Press. lbs. per sq. in.	Outs. dia. in.	Ins. dia. in.	Weight per ft. exclusive of hub-lb.	*K* =current for one milli-volt drop per ft. of continuous pipe. Amperes.
4	N	A	...	...	4.80	4.12	14.9	10.3
4	N	C	...	...	4.80	4.08	15.7	10.9
4	N	E	...	...	4.80	4.02	16.9	11.7
4	G	..	...	...	4.80	4.00	17.2	12.0
4	W	A	100	43	4.80	3.96	18.0	12.5
4	N	G	...	...	5.00	4.16	18.9	13.1
4	N	I	...	...	5.00	4.10	20.0	13.9
4	W	B	200	86	5.00	4.10	20.0	13.9
4	N	K	...	...	5.00	4.04	21.3	14.8

*W = American Water Works Association Standard.
N = New England Water Works Association Standard.
G = American Gas Institute Standard.
† = As used by the American Water Works Association and the New England Water Works Association.

TABLE FOR DETERMINATION OF CURRENT FLOW ON STANDARD CAST IRON PIPE FROM MILLI-VOLT DROP ALONG CONTINUOUS LENGTH OF PIPE BETWEEN JOINTS. *(Continued.)*

CLASSIFICATION					ACTUAL DIMENSIONS			
Nominal. Dia.in.	*Association Standard	Class Letter †	Head Feet	Press. lbs. per sq. in.	Outs. dia. in.	Ins. dia. in.	Weight per ft. exclusive of hub-lb.	K = current for one milli-volt drop per ft. of continuous pipe. Amperes.
4	W	C	300	130	5.00	4.04	21.3	14.8
4	W	D	400	173	5.00	3.96	22.8	15.8
6	N	A	...	...	6.90	6.14	24.3	16.9
6	N	C	...	...	6.90	6.06	26.7	18.5
6	G	..	...	...	6.90	6.04	27.2	18.9
6	W	A	100	43	6.90	6.02	27.8	19.3
6	N	E	...	...	6.90	5.98	29.1	20.2
6	W	B	200	86	7.10	6.14	31.1	21.6
6	N	G	...	...	7.10	6.10	32.4	22.5
6	W	C	300	130	7.10	6.08	32.9	22.8
6	N	I	...	...	7.10	6.02	34.8	24.2
6	W	D	400	173	7.10	6.00	35.3	24.5
6	W	E	500	217	7.22	6.06	37.7	26 2
6	W	F	600	260	7.22	6.00	39.6	27.4
6	W	G	700	304	7.38	6.08	42.8	29.7
6	W	H	800	347	7.38	6 00	45.2	31.4
8	N	A	...	...	9.05	8.21	35.5	24.7
8	G	..	...	...	9.05	8.15	37.9	26.3
8	W	A	100	43	9.05	8.13	38.7	26.9
8	N	C	...	...	9.05	8.09	40.3	28.0
8	W	B	200	86	9.05	8.03	42.7	29.6
8	N	E	...	...	9.05	7.99	44.3	30.7
8	W	C	300	130	9.30	8.18	47.9	33.3
8	N	G	...	...	9.30	8.14	49.6	34.5
8	W	D	400	173	9.30	8.10	51.2	35.5
8	N	I	...	...	9.30	8.04	53.6	37.2
8	W	E	500	217	9.42	8.10	56.7	39.4
8	W	F	600	260	9.42	8.00	60.6	42.1
8	W	G	700	304	9.60	8.10	65.0	45.1
8	W	H	800	347	9.60	8.00	69.0	48.0
10	N	A	...	..	11.10	10.16	49.0	34.0
10	G	..	...	...	11.10	10.12	51.0	35.4
10	N	B	...	...	11.10	10.10	51.9	36.1

TABLE FOR DETERMINATION OF CURRENT FLOW ON STANDARD CAST IRON PIPE FROM MILLI-VOLT DROP ALONG CONTINUOUS LENGTH OF PIPE BETWEEN JOINTS. (*Continued.*)

Classification					Actual Dimensions			
Nominal. Dia.in.	*Association Standard	Class Letter †	Head Feet	Press. lbs. per sq. in.	Outs. dia. in.	Ins. dia. in.	Weight per ft. exclusive of hub-lb.	K-current for one millivolt drop per ft. of continuous pipe. Amperes.
10	W	A	100	43	11.10	10.10	51.9	36.1
10	N	C	...	...	11.10	10.04	54.9	38.1
10	N	D	...	...	11.10	9.98	57.9	40.2
10	W	B	200	86	11.10	9.96	58.9	40.9
10	N	E	...	...	11.40	10.20	63.6	44.1
10	W	C	300	130	11.40	10.16	65.5	45.5
10	N	F	...	...	11.40	10.14	66.5	46.2
10	N	G	...	...	11.40	10.06	70.5	49.0
10	W	D	400	173	11.40	10.04	71.5	49.7
10	N	H	...	...	11.40	10.00	73.5	51.1
10	W	E	500	217	11.60	10.12	78.7	54.6
10	W	F	600	260	11.60	10.00	84.6	58.8
10	W	G	700	304	11.84	10.12	92.4	64.1
10	W	H	800	347	11.84	10.00	98.5	68.4
12	N	A	...	...	13.20	12.22	61.1	42.5
12	N	B	...	...	13.20	12.14	65.9	45.7
12	G	..	...	...	13.20	12.12	67.0	46.5
12	W	A	100	43	13.20	12.12	67.0	46.5
12	N	C	...	...	13.20	12.06	70.6	49.0
12	N	D	...	...	13.20	11.98	75.3	52.3
12	W	B	200	86	13.20	11.96	76.4	53.0
12	N	E	...	...	13.50	12.20	81.9	56.8
12	W	C	300	130	13.50	12.14	85.5	59.4
12	N	F	...	...	13.50	12.12	86.6	60.2
12	N	G	...	...	13.50	12.04	91.5	63.6
12	W	D	400	173	13.50	12.00	93.8	65.1
12	N	H	...	...	13.50	11.96	96.2	66.8
12	W	E	500	217	13.78	12.14	104.0	72.3
12	W	F	600	260	13.78	12.00	112.0	77.9
12	W	G	700	304	14.08	12.14	125.0	86.7
12	W	H	800	347	14.08	12.00	133.0	92.4
14	N	A	...	...	15.30	14.24	76.8	53.4
14	N	B	...	...	15.30	14.16	82.3	57.1
14	W	A	100	43	15.30	14.16	82.3	57.1

TABLE FOR DETERMINATION OF CURRENT FLOW ON STANDARD CAST IRON PIPE FROM MILLI-VOLT DROP ALONG CONTINUOUS LENGTH OF PIPE BETWEEN JOINTS. (*Continued.*)

Classification					Actual Dimensions			
Nominal. Dia.in.	*Association Standard	Class Letter †	Head Feet	Press. lbs. per sq. in.	Outs. dia. in.	Ins. dia. in.	Weight per ft. exclusive of hub-lb.	K = current for one milli-volt drop per ft. of continuous pipe. Amperes.
14	N	C	...	...	15.30	14.08	87.9	61.0
14	N	D	...	...	15.30	13.98	94.8	65.8
14	W	B	200	86	15.30	13.98	94.8	65.8
14	N	E	...	...	15.65	14.25	103.0	71.4
14	W	C	300	130	15.65	14.17	108.0	75.0
14	N	F	...	...	15.65	14.15	109.0	76.2
14	N	G	...	...	15.65	14.07	115.0	80.0
14	W	D	400	173	15.65	14.01	119.0	82.8
14	N	H	...	...	15.65	13.99	121.0	83.9
14	W	E	500	217	15.98	14.18	133.0	92.4
14	W	F	600	260	15.98	14.00	145.0	101.0
14	W	G	700	304	16.32	14.18	160.0	111.0
14	W	H	800	347	16.32	14.00	172.0	120.0
16	N	A	...	...	17.40	16.30	90.9	63.1
16	N	B	...	...	17.40	16.20	98.9	68.6
16	W	A	100	43	17.40	16.20	98.9	68.6
16	G	..	...	...	17.40	16.16	102.0	70.7
16	N	C	...	...	17.40	16.10	107.0	74.1
16	N	D	...	...	17.40	16.00	115.0	79.6
16	W	B	200	86	17.40	16.00	115.0	79.6
16	N	E	...	...	17.80	16 30	125.0	87.1
16	N	F	...	...	17.80	16.20	133.0	92.6
16	W	C	300	130	17.80	16.20	133.0	92.6
16	N	G	...	...	17.80	16.10	141.0	98.2
16	W	D	400	173	17.80	16.02	147.0	102.3
16	N	H	...	...	17.80	16.00	149.0	103.5
16	W	E	500	217	18.16	16.20	165.0	114.5
16	W	F	600	260	18.16	16.00	181.0	125.5
16	W	G	700	304	18.54	16.18	201.0	139.5
16	W	H	800	347	18.54	16.00	215.0	149.0
18	N	A	...	...	19.25	18.11	104.0	72.5
18	N	B	...	...	19.25	17.99	115.0	79.8
18	W	A	100	43	19.50	18.22	118.0	82.2
18	N	C	...	...	19.50	18.12	127.0	88.5
18	N	D	...	...	19.50	18.00	138.0	95.8
18	W	B	200	86	19.50	18.00	138.0	95.8

TABLE FOR DETERMINATION OF CURRENT FLOW ON STANDARD CAST IRON PIPE FROM MILLI-VOLT DROP ALONG CONTINUOUS LENGTH OF PIPE BETWEEN JOINTS. (*Continued.*)

Classification					Actual Dimensions			K = current for one milli-volt drop per ft. of continuous pipe. Amperes.
Nominal. Dia.in.	*Association Standard	Class Letter †	Head Feet	Press. lbs. per sq. in.	Outs. dia. in.	Ins. dia. in.	Weight per ft. exclusive of hub-lb.	
18	N	E	...	...	19.70	18.10	148.0	103.0
18	N	F	...	...	19.70	17.98	159.0	110.4
18	W	C	300	130	19.92	18.18	162.0	113.0
18	W	D	400	173	19.92	18.00	178.0	123.8
18	W	E	500	217	20.34	18.20	202.0	140.5
18	W	F	600	260	20.34	18.00	220.0	152.6
18	W	G	700	304	20.78	18.22	245.0	170.0
18	W	H	800	347	20.78	18.00	264.0	183.3
20	N	A	...	...	21.30	20.10	122.0	84.6
20	N	B	...	...	21.30	19.98	134.0	93.0
20	W	A	100	43	21.60	20.26	137.0	95.4
20	G	..	...	...	21.60	20.24	140.0	97.0
20	N	C	...	...	21.60	20.16	147.0	102.5
20	N	D	...	...	21.60	20.02	161.0	112.0
20	W	B	200	86	21.60	20.00	163.0	113.0
20	N	E	...	...	21.90	20.20	175.0	122.0
20	N	F	...	...	21.90	20.06	189.0	131.0
20	W	C	300	130	22.06	20.22	191.0	132.0
20	W	D	400	173	22.06	20.00	212.0	148.0
20	W	E	500	217	22.54	20.24	241.0	167.0
20	W	F	600	260	22.54	20.00	265.0	184.0
20	W	G	700	304	23.02	20.24	295.0	205.0
20	W	H	800	347	23.02	20.00	319.0	221.0
24	N	A	...	...	25.40	24.12	156.0	108.0
24	N	B	...	...	25.40	23.96	174.0	121.0
24	G	..	...	...	25.80	24.28	187.0	130.0
24	W	A	100	43	25.80	24.28	187.0	130.0
24	N	C	...	...	25.80	24.20	196.0	136.0
24	N	D	...	...	25.80	24.04	215.0	149.0
24	W	B	200	86	25.80	24.02	217.0	151.0
24	N	E	...	...	26.10	24.20	234.0	163.0
24	N	F	...	...	26.10	24.04	253.0	176.0
24	W	C	300	130	26.32	24.24	258.0	179.0
24	W	D	400	173	26.32	24.00	286.0	198.0
24	W	E	500	217	26.90	24.28	328.0	228.0
24	W	F	600	260	26.90	24.00	362.0	251.0

TABLE FOR DETERMINATION OF CURRENT FLOW ON STANDARD CAST IRON PIPE FROM MILLI-VOLT DROP ALONG CONTINUOUS LENGTH OF PIPE BETWEEN JOINTS. (*Continued.*)

Classification					Actual Dimensions			K = current for one milli-volt drop per ft. of continuous pipe. Amperes.
Nominal. Dia. in.	*Association Standard	Class Letter †	Head Feet	Press. lbs. per sq. in.	Outs. dia. in.	Ins. dia. in.	Weight per ft. exclusive of hub-lb.	
30	N	A	...	...	31.60	30.18	215.0	149.0
30	N	B	...	...	31.60	29.98	245.0	170.0
30	G	..	...	...	31.74	30.04	257.0	179.0
30	W	A	100	43	31.74	29.98	266.0	185.0
30	N	C	...	...	32.00	30.18	277.0	192.0
30	N	D	...	...	32.00	29.98	306.0	213.0
30	W	B	200	86	32.00	29.94	312.0	217.0
30	N	E	...	...	32.40	30.20	337.0	234.0
30	N	F	...	...	32.40	30.00	367.0	255.0
30	W	C	300	130	32.40	30.00	367.0	255.0
30	W	D	400	173	32.74	30.00	422.0	292.0
30	W	E	500	217	33.10	30.00	479.0	333.0
30	W	F	600	260	33.46	30.00	537.0	373.0
36	N	A	...	...	37.80	36.22	287.0	199.0
36	N	B	...	...	37.80	36.00	326.0	226.0
36	G	..	...	...	37.96	36.06	345.0	239.0
36	W	A	100	43	37.96	35.98	358.0	248.0
36	N	C	...	...	38.30	36.26	373.0	259.0
36	N	D	...	...	38.30	36.04	412.0	286.0
36	W	B	200	86	38.30	36.00	418.0	290.0
36	N	E	...	...	38.70	36.20	459.0	319.0
36	W	C	300	130	38.70	35 98	497.0	346.0
36	N	F	...	...	38.70	35.96	502.0	349.0
36	W	D	400	173	39.16	36.00	581.0	404.0
36	W	E	500	217	39.60	36.00	666.0	463.0
36	W	F	600	260	40 04	36.00	753.0	523.0
42	N	A	...	...	44.00	42.26	368.0	256.0
42	N	B	...	...	44.00	42.00	422.0	293.0
42	G	..	...	...	44.20	42.06	452.0	314.0
42	W	A	100	43	44.20	42.00	465.0	323.0
42	N	C	...	...	44.50	42.24	480.0	333.0
42	N	D	...	...	44.50	41.96	538.0	374.0
42	W	B	200	86	44.50	41.94	542.0	376.0
42	N	E	...	...	45.10	42.30	600.0	416.0
42	N	F	...	...	45.10	42.04	654.0	454.0

TABLE FOR DETERMINATION OF CURRENT FLOW ON STANDARD CAST IRON PIPE FROM MILLI-VOLT DROP ALONG CONTINUOUS LENGTH OF PIPE BETWEEN JOINTS. (*Continued.*)

Classification					Actual Dimensions			K = current for one milli-volt drop per ft. of continuous pipe. Amperes.
Nominal dia. in.	†Association Standard	Class Letter †	Head Feet	Press. lbs. per sq. in.	Outs. dia. in.	Ins. dia. in.	Weight per ft. exclusive of hub-lb.	
42	W	C	300	130	45.10	42.02	657.0	456.0
42	W	D	400	173	45.58	42.02	763.0	530.0
48	N	A	...	...	50.20	48.30	459.0	319.0
48	N	B	...	...	50.20	48.00	529.0	367.0
48	N	C	...	...	50.80	48.30	608.0	422.0
48	G	..	...	...	50.50	47.98	608.0	422.0
48	W	A	100	43	50.50	47.98	608.0	422.0
48	N	D	...	...	50.80	48.00	678.0	471.0
48	W	B	200	86	50.80	47.96	686.0	477.0
48	N	E	...	...	51.40	48.30	757.0	526.0
48	N	F	...	...	51.40	48.00	828.0	575.0
48	W	C	300	130	51.40	47.98	832.0	578.0
48	W	D	400	173	51.98	48.06	961.0	667.0
54	N	A	...	...	56.40	54.34	559.0	388.0
54	N	B	...	...	56.40	54.00	650.0	452.0
54	W	A	100	43	56.66	53.96	731.0	508.0
54	N	C	...	...	57.10	54.36	750.0	521.0
54	N	D	...	...	57.10	54.02	840.0	583.0
54	W	B	200	86	57.10	54.00	845.0	586.0
54	N	E	...	...	57.80	54.26	946.0	657.0
54	N	F	...	...	57.80	54.00	1041.0	723.0
54	W	C	300	130	57.80	54.00	1041.0	723.0
54	W	D	400	173	58.40	53.94	1230.0	854.0
60	N	A	...	...	62.60	60.40	664.0	460.0
60	N	B	...	...	62.60	60.00	782.0	543.0
60	W	A	100	43	62.80	60.02	836.0	581.0
60	N	C	...	...	63.40	60.40	910.0	632.0
60	W	B	200	86	63.40	60.06	1010.0	701.0
60	N	D	...	...	63.40	60.00	1028.0	714.0
60	N	E	...	...	64.20	60.40	1160.0	806.0
60	W	C	300	130	64.20	60.20	1220.0	848.0
60	N	F	...	...	64.20	60.00	1280.0	889.0
60	W	D	400	173	64.82	60.06	1455.0	1010.0
72	W	A	100	43	75.34	72.08	1178.0	819.0
72	W	B	200	86	76.00	72.10	1415.0	983.0
72	W	C	300	130	76.88	72.10	1745.0	1212.0
84	W	A	100	43	87.54	84.10	1445.0	1005.0
84	W	B	200	86	88.54	84.10	1878.0	1304.0

101. Resistance of Standard Steel or Wrought Iron Pipe.

TABLE 10

STANDARD STEEL (Or Wrought Iron) PIPE.

(Based on Resistance of steel 0.00021 ohms per lb. ft. Based on resistance of wrought iron 0.000181 ohm per lb. ft.)

Nominal dia. in.	Classification	Actual Dimensions: Outside diameter inches	Actual Dimensions: Inside diameter inches	Weight per ft. plain ends-steel-lb.	K = current for one millivolt drop per ft. of continuous pipe-amperes.: Steel	K: Wrought iron
1/8	S	0.405	0.269	0.244	1.16	1 32
1/8	X	0.405	0.215	0.314	1.50	1.70
1/4	S	0.540	0.364	0.424	2.02	2.30
1/4	X	0.540	0.302	0.535	2.55	2.90
3/8	S	0.675	0.493	0.567	2.70	3.07
3/8	X	0.675	0.423	0.738	3.51	4.00
1/2	S	0.840	0.622	0.850	4.05	4.60
1/2	X	0.840	0.546	1.09	5.18	5.88
1/2	XX	0.840	0.252	1.71	8.16	9.28
3/4	S	1.050	0.824	1.13	5.38	6.11
3/4	X	1.050	0.742	1.47	7.03	7.98
3/4	XX	1.050	0.434	2.44	11.6	13.2
1	S	1.315	1.049	1.68	7.99	9.09
1	X	1.315	0.957	2.17	10.3	11.8
1	XX	1.315	0.599	3.66	17.4	19.8
1 1/4	S	1.660	1.380	2.27	10.8	12.3
1 1/4	X	1.660	1.278	3.00	14.3	16.2
1 1/4	XX	1.660	0.896	5.21	24.8	28.2
1 1/2	S	1.900	1.610	2.72	12.9	14.7
1 1/2	X	1.900	1.500	3.63	17.3	19.6
1 1/2	XX	1.900	1.100	6.41	30.5	34.7
2	S	2.375	2.067	3.65	17.4	19.8
2	X	2.375	1.939	5.02	23.9	27.2
2	XX	2.375	1.503	9.03	43.0	48.8
2 1/2	S	2.875	2.469	5.79	27.6	31.4
2 1/2	X	2.875	2.323	7.66	36.5	41.5
2 1/2	XX	2.875	1.771	13.69	65.2	74.2
3	S	3.500	3.068	7.57	36.0	41.0
3	X	3.500	2.900	10.2	48.8	55.6
3	XX	3.500	2.300	18.6	88.5	101.0
3 1/2	S	4.000	3.548	9.11	43.4	49.3
3 1/2	X	4.000	3.364	12.5	59.6	67.8
3 1/2	XX	4.000	2.728	22.8	109.0	124.0
4	S	4.500	4.026	10.8	51.4	58.4
4	X	4.500	3.826	15.0	71.3	81.1
4	XX	4.500	3.152	27.5	131.0	149.0

STANDARD STEEL (OR WROUGHT IRON) PIPE. *Continued.*

Nominal dia. in.	Classification	Actual Dimensions: Outside diameter inches	Actual Dimensions: Inside diameter inches	Weight per ft. plain ends-steel-lb.	*K* = current for one millivolt drop per ft. of continuous pipe-amperes. Steel	Wrought iron
4 1/2	S	5.000	4.506	12.5	59.8	67.9
4 1/2	X	5.000	4.290	17.6	83.9	95.3
4 1/2	XX	5.000	3.580	32.5	155.0	176.0
5	S	5.563	5.047	14.6	69.7	79.2
5	X	5.563	4.813	20.8	98.9	112.0
5	XX	5.563	4.063	38.5	183.0	209.0
6	S	6.625	6.065	19.0	90.3	103.0
6	X	6.625	5.761	28.6	136.0	155.0
6	XX	6.625	4.897	53.2	253.0	288 0
7	S	7.625	7 023	23.5	112.0	127.0
7	X	7.625	6.625	38.0	181.0	206.0
7	XX	7.625	5.875	63.1	300.0	342.0
8	S	8.625	8.071	24.7	118.0	134 0
8	S	8.625	7.981	28.5	136.0	155.0
8	X	8.625	7.625	43 4	206.0	235.0
8	XX	8.625	6.875	72.4	345 0	392.0
9	S	9.625	8.941	33.9	161.0	184.0
9	X	9.625	8.625	48.7	232.0	264.0
10	S	10.750	10.192	31.2	149.0	169.0
10	S	10.750	10.136	34.2	163.0	185.0
10	S	10.750	10.020	40.5	192.0	219.0
10	X	10.750	9.750	54.7	261.0	297.0
11	S	11.750	11.000	45.6	217.0	247.0
11	X	11.750	10.750	60.1	286.0	326.0
12	S	12.750	12.090	43 8	208.0	237.0
12	S	12.750	12.000	49.6	236.0	269.0
12	X	12.750	11.750	65 4	311.0	354.0
13	S	14.000	13.250	54.6	260.0	296.0
13	X	14.000	13.000	72 1	343 0	391.0
14	S	15.000	14.250	58 6	279.0	317.0
14	X	15.000	14.000	77 4	369.0	420.0
15	S	16.000	15.250	62.6	298.0	339.0
15	X	16.000	15.000	82.8	394.0	449.0

S = Standard pipe.
X = Extra strong pipe.
XX = Double extra strong pipe.

102. Resistance of Lead Cable Sheaths.

TABLE 11.

TABLE FOR DETERMINING CURRENT ON LEAD CABLE SHEATHS FROM VOLTAGE DROP IN MEASURED LENGTH OF SHEATH.

Resistivity, 1 ft. length, 1 sq. in. sectional area = 0.00010 ohm

Outside diam. of lead sheath (in.)	Thickness of lead sheath (64th in.)	Resistance of lead sheath (ohm per ft.)	Current for 1 millivolt per ft. (amp.)	Outside diam. of lead sheath (in.)	Thickness of lead sheath (64th in.)	Resistance of lead sheath (ohm per ft.)	Current for 1 millivolt per ft. (amp.)
0.50	4	0.001163	0.860	2.00	6	0.0001781	5.61
0.50	5	0.000965	1.036	2.00	7	0.0001538	6.50
0.50	6	0.000836	1.196	2.00	8	0.0001359	7.36
0.625	4	0.000906	1.104	2 125	6	0.0001672	5.98
0.625	5	0.000745	1.343	2.125	7	0.0001443	6.93
0.625	6	0.000640	1.563	2.125	8	0.0001273	7.86
0.75	4	0.000741	1.350	2.25	6	0.0001575	6.35
0.75	5	0.000606	1.650	2.25	7	0.0001359	7.36
0.75	6	0.000518	1.931	2.25	8	0.0001198	8.35
0.875	4	0.000627	1.594	2.375	6	0.0001488	6.72
0.875	5	0.000511	1.957	2.375	7	0.0001284	7.79
0.875	6	0.000435	2.300	2.375	8	0.0001132	8.83
1.00	5	0.0004419	2.263	2.50	7	0.0001217	8.22
1.00	6	0.0003750	2.668	2.50	8	0.0001073	9.32
1.00	7	0.0003268	3.061	2.50	9	0.0000959	10.43
1.00	8	0.0002913	3.437				
				2.625	7	0.0001156	8.65
1.125	5	0.0003892	2.569	2.625	8	0.0001019	9.81
1.125	6	0.0003294	3.037	2.625	9	0.0000911	10.98
1.125	7	0.0002866	3.491				
1.125	8	0.0002547	3.926	2.75	7	0.0001102	9.08
				2.75	8	0.0000971	10.30
1.25	5	0.0003476	2.876	2.75	9	0.0000868	11.53
1.25	6	0.0002939	3.404				
1.25	7	0.0002552	3.918	2.875	7	0.0001050	9.51
1.25	8	0.0002265	4.415	2.875	8	0.0000927	10.79
				2.875	9	0.0000828	12.08
1.375	5	0.0003142	3.183				
1.375	6	0.0002650	3.773	3.00	8	0.0000887	11.28
1.375	7	0.0002299	4.35	3.00	9	0.0000792	12.62
1 375	8	0.0002038	4.91	3.00	10	0.0000716	13.96
1.50	6	0.0002416	4.14	3.125	8	0.0000849	11.77
1.50	7	0.0002092	4.78	3.125	9	0.0000758	13.18
1.50	8	0.0001853	5.40	3.125	10	0.0000686	14.58
1.625	6	0.0002218	4.51	3.25	8	0.0000815	12.27
1.625	7	0.0001920	5.21	3.25	9	0.0000728	13.74
1.625	8	0.0001698	5.89	3.25	10	0.0000659	15.19
1.75	6	0.0002051	4.88	3.375	8	0.0000783	12.77
1.75	7	0.0001772	5.64	3.375	9	0.0000700	14.29
1.75	8	0.0001567	6.38	3.375	10	0.0000633	15.83
1.875	6	0.0001906	5.25	3.50	8	0.0000755	13.24
1.875	7	0.0001648	6.07	3.50	9	0.0000674	14.84
1.875	8	0.0001456	6.87	3.50	10	0.0000609	16.42

103. Typical Report Sheets.

TIME	DATE ...... TESTED BY ...... LOCATION ...... AVE. OR ST.	POTENTIAL, CABLE TO		DUCT		WATER		GAS		TRACK				DIRECTION OF CURRENT ON CABLE	ELECTROLYSIS PITTINGS ON CABLE?	CABLES BONDED TOGETHER?	WATER IN MANHOLE?	DUCT MATERIAL?	CABLES PROTECTED?	CABLES SUPPORTED?
		+	−	+	−	+	−	+	−	+	−	+	−							
1130																				

(This shows a condensed form in convenient size for a field notebook).

CURRENT MEASUREMENTS

DATE AND TIME		Duration of Test Min.	Dist. betw. Cont. Feet	Amp. per Milli. K	Drop—Millivolts			Current—Amperes			DIRECTION.
					Max.	Min.	Ave.	Max.	Min.	Ave.	

POTENTIAL MEASUREMENTS

DATE AND TIME		Duration of Test Min.	Potential—Volts Max.	Min.	Ave.	Momentary bond Current Amp.	

FORM NO. 1

POTENTIAL SURVEY :—

CITY :— DATE :— OBSERVER :—

TIME	LOCATION	MEASUREMENTS		Duration of Test Min.	VOLTS POLARITIES REFER TO (A)			Max. Momentary Current Through Temporary Bond	REMARKS
		FROM (A)	TO (B)		Max.	Min.	Ave.		

FORM NO. 2

CURRENT SURVEY:—

CITY:— DATE:— OBSERVER:—

TIME	LOCATION	Size and Kind of Pipe	Dist. Bet. Contacts Feet	Duration of Test Min.	Direction of Current Flow	DROP IN MILLIVOLTS			CALCULATED CURRENT AMPERES			REMARKS
						Max.	Min.	Ave.	Max.	Min.	Ave.	

Form No. 3

Data sheet for Electrolysis Survey.

TESTS ON EXPOSED PIPE

City:— Date:— Time:— Observer:—

Location:—

Size and kind of pipe:—

Pavement:— Soil:—

Location of nearest trolley tracks:—

" " " " power station:—

Approximate age and condition of pipe:—

	Max.	Min.	Aver.
Duration of each test........minutes			
Potential, pipe to rails, volts	......	......	......
Current through temporary bond connection, amperes			......
Distance between contacts on pipe = ... feet			
Drop on pipe, millivolts	......	......	......
Current on pipe, amperes	......	......	......
Direction of current flow:—			

Potential to Other Pipes, Etc.:—

Simultaneous Drop Measurements for Resistance of Joints.

		Equivalent resistance	
		Feet of pipe.	Ohms.
Drop in...... feet of pipe =	millivolts		
Drop across first joints	"	....	....
" " second joint =	"	....	....