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COMITE CONSULTATIF INTERNATIONAL DES COMMUNICATIONS TELEPHONIQUES A GRANDE DISTANCE.

VI. Questions concerning the Protection of Telephone Cables against Corrosion due to Electrolysis or to Chemical Action.

English Edition,
Issued by
The International Standard Electric Corporation.
London. 1928.

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PREFACE TO THE ENGLISH EDITION.

This volume contains an unofficial translation of that part of the official French text of the proceedings of the COMITE CONSULTATIF INTERNATIONAL DES COMMUNICATIONS TELEPHONIQUES A GRANDE DISTANCE (C.C.I.) at its plenary session in Como, 5th–12th September, 1927, contained in pages 123–150 of the *Livre Rose* relating to—

"Questions concerning the Protection of Telephone Circuits against Corrosion due to Electrolysis or to Chemical Action."

INTERNATIONAL STANDARD ELECTRIC CORPORATION.

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GENERAL SUBJECT INDEX.

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COMITE CONSULTATIF INTERNATIONAL DES COMMUNICATIONS TELEPHONIQUES A GRANDE DISTANCE.

Plenary Session, Como.
5th—12th September, 1927.

VI. QUESTIONS CONCERNING THE PROTECTION OF TELEPHONE CABLES AGAINST CORROSION DUE TO ELECTROLYSIS OR TO CHEMICAL ACTION.

A. RECOMMENDATIONS.

1. The International Consultatif Committee—

Considering :

That research on faults on underground cables and the repair of these faults may lead to considerable cost; that the interruptions in the service which may result from the presence of these faults should be avoided with great care; that even after the repair has been carried out as well as possible, the quality of the cable may be decreased and its normal life reduced.

Unanimously advises :

That it is desirable in the interests of long-distance telephony to publish certain information capable of assisting the different Administrations in overcoming the effects of electrolysis due to return currents from electric traction and the effects of chemical action on lead-covered cables.

2. The International Consultatif Committee—

Considering :

That certain appropriate measures taken at the time of installation or during the maintenance of telephone cables can reduce the importance of electrolytic effects, the most effective means of overcoming the damage is certainly to diminish the importance of their cause, that is to say, to prevent the establishment of excessive difference of potentials between the return conductors of the traction current and the lead sheath of the cables;

That this result can be obtained by observing certain technical rules during the installation of the traction lines, by means of a proper adaptation of the feeding network and of the return current network to the operating conditions of these lines, and by means of particular care taken in the installation of this network;

That, nevertheless, in order to be able to define with sufficient precision these different precautions, it is necessary to take into account the general conditions of operation of the traction system;

That in the case of railway lines of general interest, the present knowledge on the question does not yet permit the establishment of rules which would be applicable to these lines, but that the present development of electric traction on the networks of general interest justifies the continuation of the studies undertaken in this respect;

That, on the other hand, the adoption of proper precautions to be taken for each particular case, in the maintenance of telephone cables, assumes often sufficient knowledge of the operating conditions of the neighbouring railway lines; also that the interests of the telephone Administrations do not differ, in this case, from the interests of other Administrations,

Unanimously advises:

That it is desirable that the study of measures of precaution against stray currents should be followed by the C.C.I. in collaboration with the international organisations representing officially the different interests in question, such as the International Union of Tramways and Local Railways and the International Union of Railways;

That it is to be recommended that each telephone Administration, while applying to its underground networks measures capable of increasing their security from risk of damage due to electrolysis, will enter into collaboration with the Administrations of electric traction networks, as well as with the other interested Administrations (water, gas, electric distribution) in order to study in common, in each particular case, the best conditions for installation, maintenance and supervision of the networks and jointly to take all useful precautions.

3. The International Consultatif Committee—

Considering:

That the proposed Guiding Principles (Section B) only deals with the employment of earth plates (déversoirs) and the practice of electric drainage with extreme reserve, a definite and unanimous opinion not yet having been made;

Unanimously advises:

That the attention of the interested Administrations should be again drawn to the necessity for continuing the study of these questions.

4. The International Consultatif Committee—

Considering:

That new information will be useful in order to be able to decide on the terms of the Guiding Principles concerning the measures to be taken for the protection of cables against electrolytic corrosion, particularly in connection with the protective measures concerning the electric traction network;

Unanimously advises:

That it is convenient to defer the study of the question of the protection of cables against electrolysis, due to the different observations which will be presented on the subject of the proposed Guiding Principles;

That it should be understood that the numerical values occurring in the text of the proposed Guiding Principles should only be considered at present as indications.

5. The International Consultatif Committee—

Considering :

That the rules which have been indicated in the proposed Guiding Principles concerning the protection of cables against chemical action contain, because of the great diversity in the measures adopted and the experiments carried out in the different countries, only general indications susceptible of considerable exceptions in special cases;

Unanimously advises :

That the different Administrations should be invited to examine these rules, taking into account the special conditions that they meet in their operation (properties of the soil, systems of construction . . . .) and to indicate to the General Secretary of the C.C.I. the new experimental results that they obtain.

B. PROPOSED TEXT OF THE GUIDING PRINCIPLES CONCERNING THE MEASURES TO BE TAKEN FOR THE PROTECTION OF CABLES AGAINST ELECTROLYTIC CORROSION.

In elaborating the present Guiding Principles, the C.C.I. proposes to gather together certain information capable of assisting the different Administrations to overcome the effects of electrolysis due to return currents from electric traction.

At the present time, while it is relatively easy to detail the principle of most of the technical measures to be taken, it is scarcely possible to fix their precise limits. The measures that can be proposed can only result in a compromise between the technical aim to be attained and the economical possibilities of realising this.

It has seemed useful, nevertheless, in order to fix the ideas, to give some precise numerical values for the limits to apply to the technical measures recommended. It is in this spirit that the numerical values in the text of the Guiding Principles have been determined.

From another point of view the Guiding Principles can only be considered as expressing the opinion of the majority of the technical advisors taking part in the work of the C.C.I., certain Administrations not accepting all the numerical limits proposed. All the questions of an administrative and economic order, and, in particular, all the questions of regulations and legislation relative to the problem of the neighbourhood of communication lines, are outside the sphere of the Committee and have been left on one side.

In particular the Committee has abstained from entering into details of the rules of procedure which should be followed in the reports between the telephone Administrations and the services of electric traction, production or distribution of electricity. It believes, however, that it can make a very general recommendation.

In order to obtain every advantage from the measures to be taken for the protection of telephone lines, and in order to facilitate their practical application, it is desirable that the telephone or electrical services interested should collaborate with the greatest goodwill. The reciprocal interchange, in a systematic and regular manner, of all useful information relating to the construction of existing or projected lines, to the changes of conditions of operation of existing or proposed installations in the neighbourhood, is much to be recommended.

(a) **General.**

1. The danger of electrolytic corrosion results only from direct-current electrification using the rails as conductors. According to tests made up to the present, it appears that stray currents resulting from alternating-current installations of usual frequency do not exercise any harmful influence on metallic masses in the soil.

Experience has shown that a network of conduits or of cables can be considered as practically free from corrosion due to stray currents, if it nowhere approaches closer than 200 metres to the rails of an electrified railway.

The present Guiding Principles should, therefore, only apply in the case of railways or tramways electrified with direct current, using the rails as conductors and being at some point less than 200 metres from the cable or the conduit.

These arrangements do not concern railways with independent tracks when these are insulated from the earth throughout the whole network (wood sleepers, special insulation of tracks at level crossings, etc.).

They do not concern, also, railway lines of general interest, as the present knowledge on the question does not allow us to give rules which can be applied to these lines.

2. From the point of view of the danger to which underground metallic conduits are exposed it is necessary to distinguish, in a traction network established along a road, between the region in which the pipes and the cables are at a potential less than that of the rails, where, as a result, the current enters the conduits, and that in which the conduits have a voltage greater than that of the rails and where, in consequence, the current leaves the former.

In the following text are used the expressions " entrance zone " to designate the zone where the stray currents enter the sheath of the cables, and " exit zone " (or zone of anode corrosion), the zone where the currents leave the sheath.

3. When conditions exist so that an attack of pipes or cables by stray currents from the traction installation can be produced, it is necessary to apply special measures to avoid dangerous corrosion as much as possible.

4. Measures of protection should be applied in the first instance to the construction and operation of the electric traction system, the latter being the first cause of the stray currents.

Besides, these measures are generally easier to apply technically than equally effective measures applied to the cable. The latter can, in general, only be usefully applied in new installations or at the moment of an important reconstruction. When installing new metallic conduits in the neighbourhood of existing or projected traction systems, these conduits should themselves be protected against corrosion by appropriate measures.

In addition, it should be remarked that, apart from the electrolytic or chemical action which they can produce, the stray currents can be harmful by themselves—for example, where, at the crossing of tracks of general interest of which the rails carry signalling currents, they are capable of using these tracks. This consideration is added to the preceding ones in order to justify the necessity of limiting as much as possible the currents which pass in the earth in power installation.

5. The measures proposed here result from a compromise between the technical aim to be attained and the economic possibilities of realising this : although they are not sufficient to overcome all danger from corrosion, they will probably ensure that the normal life of a cable will not be notably reduced by electrolysis.

6. From the technical point of view it is desirable that the application of these measures be made the object of a systematic collaboration between all the interested Administrations (tramways, telephones, electric distribution, gas, water, etc.), in particular it is desirable that the telephone Administrations participate in tests with the object of verifying the satisfactory state of the electric traction networks.

(b) Protective Measures to be Applied to Electric Traction Networks.

1. In order to diminish the amount of stray currents it is necessary to :—

(*a*) Increase the contact resistance between the rails and the earth.

(*b*) Increase the conductivity of the rails (including the joints).

(*c*) Decrease the differences of potential between the rails and the earth.

2. It is necessary as far as possible to place the rails on a well-drained sub-structure of low conductivity.

3. The conductivity of the rails themselves being determined by their cross-section, it is necessary to take great care to maintain a good and constant conductivity at all the joints.

4. The resistance of the joint should not be greater than that of 3 metres of rail, exceptions being made at points and crossings. Further, the increase in electric resistance of a given section of track due to the joints should not exceed a mean of 10 per cent. of the resistance of the rails of this section without joints (*see* note at the bottom of page 12).

At points and crossings, the joints of the grooved rails (rails *à gorge*) are not accessible because they are buried in the roadway; further, they are subject to greater mechanical forces, particularly in the central pieces or tongues (*cœurs*). It is, therefore, not possible to apply at these joints the same precautions as at the other parts of the track. For this reason, at points and crossings the joints of the grooved rails should satisfy the following conditions :—

(*a*) The joints should not, immediately after their construction or after an important repair, have a resistance greater than that of 3 metres of rail.

(*b*) The joints which on a later test show a resistance higher than that of 20 metres of rail should be put into a good condition with the shortest possible delay.

At points with flanged rails, the inside rails cannot be considered as helping to conduct the current because, in general, the movable points are not shunted by bonds. In the same way, the central piece or tongue of points and crossings in flanged rails can only be bridged by bonds of great length, and, consequently, of high resistance. This is why it is necessary that the resistance of joints in the two exterior rails should be always kept as small as possible. This condition is easy to fulfil, due to the fact that the joints of flanged rails are easily accessible. Consequently, at points and crossings the joints of flanged rails should satisfy the following conditions :—

(c) The resistance of each joint of the two exterior rails should never exceed the resistance of 3 metres of rail.

(d) If the transverse connections satisfy the conditions of paragraph 6, special bonds can be dispensed with for bridging the point rail, rails and tongues.

5. In order always to keep the track in the best possible condition from the point of view of its conductivity, it is necessary to check once a year all points and crossings which regularly carry current, as well as joints in sections of track* for which the calculation has furnished a mean drop in voltage greater than 0·0005 volt per meter (the definition of the mean voltage is given in paragraph 10 below).

The resistance of all the other joints should be measured every third or fifth year. It is necessary to put these in a satisfactory state as quickly as possible, if the resistances measured are greater than the values indicated in paragraphs 3 and 4 of this section.

An exception is made for welded joints which should, nevertheless, be examined each year from the point of view of cracks. Those which are defective should be repaired.

6. In order to equalise as much as possible the current density in all of the rails of the track or of parallel tracks, cross connections are used.

At points and crossings a cross connection is placed between all the rails of the track before and after the points or the crossing.

The dimensions of the cross connections will be such that the resistance measured between any two points on the two lines of rail does not exceed per metre of distance between the two rails 1 milli-ohm in the case of grooved rails, and 1·5 milli-ohms in the case of flanged rails. Immediately before and after points or crossings in flanged rails this resistance should not exceed 0·25 milli-ohm.

7. It is possible to control the potentials at places in the rails by placing, for example, return feeders whose action will be controlled either by means of additional resistances or by means of reversible boosters with automatic regulation. It is possible also to divide the load between several generating stations.

8. The return feeders should be insulated from the earth. That the connection is good between return feeders and the rails, as well as the insulation of the feeders, should be verified at least once a year.

9. If the rails are connected to the negative pole of the generators, it is necessary to choose as far as possible for the connections between the return feeders and rails locations where the earth is dry and at some distance from important networks of pipes and cables, since it is at the connecting points of feeders to the rails where the danger of corrosion is most pronounced.

10. To ensure that the preceding measures will give satisfactory results, the limits of the differences of potential between rails and earth and the drop in potential along the rails are calculated according to the method developed in Appendix I.

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* A section of track is a continuous portion in which neither crossing, points or return feeder connections are situated.

By " differences of mean potential " or " mean drop in voltage " are meant the values given by the calculation carried out for the different sections of track, taking for the power in a given section the mean of the power actually consumed in that section during the consecutive 24 hours of a working day.

11. Experience shows that it is necessary to distinguish, from the point of view of danger of corrosion, between the tramways for which the supply depends on a single-feeder station or from a sub-station situated in the town or in the immediate suburbs (called hereafter " urban tramways "), that is to say, those which are established for the greater part in the interior of the town, and the tramways for which the supply depends on a feeder station or on a sub-station situated outside the town and the immediate suburbs (called hereafter " suburban tramways "), that is to say, those which are established for the greater part outside the town.

Suburban tramways supplied by generating stations or by a sub-station situated in the town or in its immediate suburbs are considered from the point of view of the following rules as urban tramways.

12. In each point of the zones of the territory served by an urban tramway where the stray currents leave the pipe line or the cable sheath, differences of mean potential between the rails and pipes or cable sheaths should not exceed 0·8 volt.

13. On no section of an urban tramway track should the fall in voltage per metre, calculated on the assumption of an increase in rail resistance due to the joints of 10 per cent. (*see* paragraph 3) be greater than 0·001 volt.

14. The fall in mean voltage per metre on a section of track of suburban railway calculated according to paragraph 10 should not exceed 0·0012 volt in road sections, and 0·0014 volt in the sections with separate road bed.

15. The fall in mean voltage between two points in a tramway line (urban or suburban) should not exceed a number of volts equal to twice the distance in a straight line between these two points.*

16. Measures described in Appendix II enable in practice the verification of the condition of the network. They constitute an approximate check on the results of the calculation of voltages or differences of mean voltage.

17. It is possible to diminish the danger of corrosion by changing the polarity of the contact wires.

When the positive pole is connected to the contact line, the zones of anode corrosion are located in the neighbourhood of the connecting points of the return feeders.

When it is the negative pole which is connected to the contact line the zones of anode corrosion are located in the outlying parts—that is to say, the exit zones tend to follow the movements of the locomotives.

In order to reduce the harmful effect of stray currents it is possible to make use of either a periodic reversal of the polarity of the contact wire (which in the case of a daily reversal can produce a reduction of about three-quarters), or a three-conductor feeder system.

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* Although the conditions of paragraphs 13 and 14 seem to be sufficient from the point of view of electrolytic corrosion, other considerations, such as, in particular, telegraphy or signalling on telephone lines with earth return, render it desirable to fix a maximum limit for the difference of instantaneous voltage between any two points of tramway track.

The study of local conditions will permit in each case a choice of the best solution.

It is also necessary to remark that the periodic reversal of the polarity of the contact wires produces great difficulties in the operation of networks supplied by several sub-stations. In addition, in large towns where separate networks are installed and inter-connected at crossing points, the adoption of this measure on one of the networks necessitates the establishment of special arrangements to ensure, at the crossing points, the insulation of this network from the others.

(c) Protective Measures Applied to Underground Cable Networks.

1. In order to avoid electrolytic corrosion due to stray currents leaving the metallic sheaths of cables, it is necessary to attempt to reduce as much as possible the flow of stray currents in the cable sheaths. In certain cases, where it is not possible to reduce sufficiently the magnitude of the stray currents, it may be advantageous to provide them with a drainage path at the point where they leave the cable sheaths.

2. The cables should be placed as far as possible from tramway installations; the crossings of the tramway lines being the dangerous points, it is necessary to reduce their number as much as possible.

3. When studying cable routes, it should not be forgotten that certain soils favour electrolytic corrosion (especially dampness, organic substances, soluble alkalies, bases and acids, etc.).

4. It is necessary to avoid as far as possible infiltrations and stagnant water in the conduits as well as in the connection boxes or in the manholes.

5. In manholes and in terminal boxes, as well as at junction points, bare cables should be connected together by means of metallic connections soldered to the sheaths.

In cases where the underground conduits containing telephone cables are constructed of metallic pipes, these should also be connected electrically at these points.

6. A simple layer of insulating paint or a thin insulating covering provides very little guarantee against penetration by water, and cannot provide a permanent protection against corrosion. Such insulating layers are often found to be dangerous, since, after a certain time, at points which have become uncovered, a more intense corrosion takes place.

7. When the insulating sheath which covers the cable sheath is sufficiently thick and is itself protected, both from the mechanical and from the chemical point of view, by armouring or by some similar arrangement (cable sheath, conduits of Zores iron, etc.), the protection against electrolytic corrosion can be considered sufficient.

8. It has been proposed in exceptional cases where there is a possibility of contact with iron bridges and other metallic structures to instal insulating joints in the cable sheath with a view to preventing electrolytic trouble. These insulating joints should only be installed at points where the ground is sufficiently dry. Nevertheless, it does not seem that the advantages presented by this method in reducing the effects of electrolysis compensate for the serious inconvenience which is to be expected in connection with the quality of the telephone transmission.

9. Earth plates buried in the earth and connected to the cable sheath (*déversoirs*) present several of the disadvantages of drainage connections*; it is advisable to restrict their use to points where the current leaves the cable sheath and never to use them in regions where it is not possible to ensure that the earth plate will never be positive with respect to the cable sheath.

It does not seem that this procedure should be recommended for the protection of cables against electrolysis due to return currents from traction networks, a change in the distribution of these currents (produced, for example, by a modification in the traction network) being capable of modifying the polarity of some of these earth plates with respect to the cable sheath.

(d) Protective Measures by means of Electric Drainage.

1. Under the heading of electric drainage is included a system comprising the use of metallic conductors for connecting to the return current network of the traction system certain points of the cable sheath which without drainage would tend to become positive with respect to the earth. The object is to conduct by a metallic path to the generating station the current which flows in the cable sheaths in such a manner as to decrease the amount of current which leaves these sheaths and enters the earth.

2. The use of drainage raises a certain number of different kinds of objections :—

This practice is very costly (cost of installation, of maintenance and of inspection high).

It can become effective as a result of accidental alteration in the distribution of the currents circulating in the cables; in particular the magnitude of these currents can become too great; on the other hand, cable may be exposed to cathode corrosion at places where the earth is of an alkaline nature.

It can become a cause of danger to telephone installations when a short circuit is produced on the traction network, and a cause of danger to the personnel dealing with the maintenance or operation of the telephone cables when the continuity of the rails has become broken by accident.

Finally, drainage, having as its effect the increase in the extent of the return current network of the traction system in all directions, can increase considerably the probability of corrosion at some point in the cable network or in neighbouring metallic conduits.

3. However, these disadvantages can be considerably decreased in certain cases—for example, when only a single traction line exists and where the route of the telephone cables is parallel to this track and has no branches. In such a case drainage connections can be permitted on the condition that a relatively small quantity of current is drained; this quantity should not exceed that which is necessary to prevent the harmful effect of electrolysis.

4. In all cases where a drainage system is adopted it is necessary that this system should be established in accordance with the following principles :—

(*a*) The most convenient point for making the connection to the cable sheath is the point where measurements show that the current leaving the cable to enter the earth is the greatest possible value. It is necessary, in order that the drainage shall

* *See* Section (d) in connection with this subject dealing specially with electric drainage.

be satisfactory, that the potential of points where the connections are arranged, which were positive with respect to the earth before the adoption of this measure, should become, on the contrary, lower than the voltage of the earth in the neighbourhood.

(*b*) Drainage connections should be installed only at the negative busbar of the traction current generator or at points where the return feeders are connected to the rails.

(*c*) The drainage should be arranged in such a way that the cable sheath being drained has throughout its length a negative potential with respect to the earth.

(*d*) It is essential to reduce all drainage to the minimum necessary for the protection of telephone cables. This can be done either by the choice of a suitable section of the conductors used for the drainage or by the use of additional resistances.

(*e*) An effective watch should be kept in order to check the conditions of operation of the drainage system: periodical measurements of drainage current are necessary. To this end all useful arrangements should be taken during the installation of the system to enable these measurements to be carried out easily.

(*f*) It is equally necessary to take care of the possibility of being able to interrupt the drainage connections at all times, when, apart from this precaution, currents could circulate of reverse polarity and of magnitude or of duration capable of leading to damage.

(*g*) It is necessary, finally, to instal fuses in drainage connections or to use circuit breakers adapted to local conditions in order to interrupt the connection in case of short circuits on the traction network.

APPENDIX I.

TO THE GUIDING PRINCIPLES CONCERNING THE MEASURES TO BE TAKEN FOR THE PROTECTION OF CABLES AGAINST ELECTROLYTIC CORROSION.

PRINCIPLE OF THE METHOD TO BE FOLLOWED FOR CALCULATING THE DISTRIBUTION OF RETURN CURRENTS IN A TRAMWAY NETWORK.

In order to avoid electrolytic corrosion it is necessary to reduce, as far as possible, differences of potential between different points of the rail and the earth.

This is obtained, particularly when the sections of track carrying too great a value of current is discharged conveniently by means of return feeders of sufficient cross-section connected to the rails at properly chosen points. The method of calculation indicated here serves as a guide in the choice of these arrangements.

It would be possible to determine exactly the distribution of return currents in the rails and in the earth as well as the distribution of potentials, if the following information was known :—

The geometric configuration as well as the electrical characteristics of the track network.

The position of the return feeders as well as their electric characteristics.

The insulation resistance of the rails with respect to earth at each point of the track network.

The conductivity of the earth at each point.

Finally, the values at each instance of the current entering the rails at each point of the network where there is a locomotive. It is evident, also, that these values of current entering the rails depend on the configuration of the feeder network and the electrical characteristics of this network, as well as on those of the machines, and, finally, on all the data given above.

Nevertheless, as the effects of electrolysis depend, not on the instantaneous values of the current, but on their integral with respect to time, it is sufficient to take into account in the calculations the mean values of the current.

It should be remarked that certain of the data necessary for the exact solution of the problem cannot be known. Nevertheless, in practice the approximate solution is relatively easy of calculation, and permits a sufficiently exact idea to be obtained of the distribution of the potential which determines the extent of the electrolytic action.

It is possible in effect to assume, in order to simplify the calculation as far as concerns the electrolytic effect, that everything takes place as if the mean values of the current supplied to the rails by the generators had the same value per unit length at all points in the same section of track.

The values of these currents that must be introduced into the calculation can be deduced, either from the readings of instruments installed in the locomotives, if it is a question of a system already established, or, in general, from empirical relations giving the consumption of the machines as a function of the weight transported, of the speed, of the gradient of the tract, etc.

In addition, for a first approximation, as long as the distribution of currents in the rail network and the distribution of potential along this network are studied, it seems permissible to neglect the losses of current along the rails.

These losses are small in general, and, in addition, the better the network is established the smaller are these losses.

The only effect of neglecting these losses will be that the differences of potential determined between the points and the rail will be larger than those present in reality.

Experience has shown that when the differences of potential calculated under these conditions do not exceed the value of 0·8 volt specified in paragraph 12 of Section B of the Guiding Principles, the damage caused by the corrosion is reduced to permissible limits.

In any case, if it is assumed that the losses of current in the earth are negligible, the presence of the earth can be neglected in the calculation of the distribution of currents in the rail network and of the distribution of potentials along this network.

This calculation can be made in the following manner :—

1. The mean linear density of the feeder current is known at each point of the rail network. The value I of the total current entering the whole network can thus be determined.

2. Currents entering the rail network can only leave by the feeders; the sum of the currents leaving by the feeders is thus equal to I.

3. Suppose, to start with, that there exists a single feeder F_1 of known position. Knowing the value of the current entering at each point, and also the value I_{F1} of the current leaving by the feeder, which in this case is equal to I, we can determine absolutely (and independently of all electrical characteristics of the feeder) the value of the current which passes each point in the rail network. This determination is made by means of Kirchhoff's laws. By applying Ohm's law the value of the potential at each point is obtained, the potential of reference being that of a point chosen arbitrarily.

Let M be any point in the network rail.

Assume the following symbols :—

I_{M1}, the mean value of the current passing the point M,

V_{M1}, the mean potential at this point (the second index 1 indicates that I_{M1} and V_{M1} have been calculated on the assumption that all the current I leaves by the feeder F_1).

4. This being so, consider the case where p feeders are used, F_1, F_2, F_i, F_p, of which the position is known.

The preceding calculation can be repeated for each feeder, assuming that it exists alone.

Denote by :

I_{M1}, I_{M2}, I_{Mi}, I_{Mp}, the different values of current which passes the same point M of the rail network.

V_{M1}, V_{M2}, V_{Mi}, V_{Mp}, the different values of potential of the same point M (the potential of reference being that of arbitrary point, but the same in all cases) calculated on the assumption of the existence of a single feeder.

It is important to note that these quantities can be calculated once and for all from the values of current entering the network and the position of the feeders, independently of all electrical characteristics of the feeders.

This having been done, denote by I_{F1}, I_{F2}, I_{Fi}, I_{Fp}, the values of currents leaving feeder F_1, F_2, F_i, F_p.

We have, therefore :

$$\sum_{i=1}^{i=p} I_{Fi} = 1 \qquad \text{.........} (1)$$

Also the value of current at a point M will be equal to :

$$I_M = \frac{\sum\limits_{i=1}^{i=p} I_{Fi}\, I_{Mi}}{\sum\limits_{i=1}^{i=p} I_{Fi}} \qquad \text{.........} (2)$$

The value of potential at point M will be :

$$V_M = \frac{\sum\limits_{i=1}^{i=p} I_{Fi}\, V_{Mi}}{\sum\limits_{i=1}^{i=p} I_{Fi}} \qquad \text{.........} (3)$$

5. Thus, on the assumptions made up to the present, the knowledge of the value of the currents leaving each feeder permits the complete determination of the distribution of current in the rail network as well as the distribution of potentials.

In the application we can start from different data, according to the object of the study. We can thus start with the value of the current which leaves the rails at each feeder. In order to obtain effectively this result, it is necessary to determine the electrical characteristics of the feeders in such a way that they satisfy certain conditions.

Let R_1, R_2, R_i, R_p be the resistance to be given to each of the feeders.

Denote by V_1, V_2, V_i, V_k, V_p, the values of potential at points *1*, 2, *i*, *k*, *p*, where these feeders are connected to the rails.

According to the general equation (3), the expression for this is :—

$$\left.\begin{aligned} V_1 &= \frac{\sum\limits_{i=1}^{i=p} I_{Fi}\, V_{1i}}{\sum\limits_{i=1}^{i=p} I_{Fi}} \\ V_k &= \frac{\sum\limits_{i=1}^{i=p} I_{Fi}\, V_{Ki}}{\sum\limits_{i=1}^{i=p} I_{Fi}} \end{aligned}\right\} \qquad \text{.........} (4)$$

As all the feeders are connected to the same busbar at the generating station, we must have :—

$$V_1 - R_1 I_{F1} = V_k - R_k I_{Fk} = V_p - R_p I_{Fp} \quad \text{.........(5)}$$

These p equations (4) and these $(p - 1)$ equations (5) are not sufficient to determine the $2p$ unknowns (values of V_k and values of R_k). We can, therefore, for example, fix arbitrary value of one of these unknowns.

It should be noted that it is nevertheless necessary, in order that the integral solution should have a physical meaning, that the values found for the different resistance should be positive.

We can also determine the distribution of return currents in the different feeders in such a way that the points where all the feeders are connected to the rails are at the same potential.

The system of equations to be solved is thus :

Relation (*1*).

The p equations (4).

To which must be added the $(p - 1)$ equation (6)

$$V_1 = V_2 = \ldots\ldots = V_k \ldots\ldots = V_p \quad \text{.........(6)}$$

There are thus, the total of $(2p)$ equations to calculate $2p$ unknowns (the values of I_{Fk} and of V_k). The solution of the problem is thus completely determined.

We can finally determine what is the distribution of currents in the rail network when the return feeders have a resistance determined in advance.

Let V_k be the value of potential at a point where feeder F_k is attached; R_k the resistance of this feeder.

The system of equations to be solved is therefore :

Relation (*1*).

The p equations (4).

The $(p - 1)$ equations (5).

There are thus, $2p$ equations to calculate $2p$ unknowns (the values of I'_{Fk} and of V_k). The solution to the problem is therefore determined.

6. In any case, when the values of the current leaving by each feeder are determined we can, by means of equation (3), calculate the distribution of potentials along the rails, the potential of reference being that of an arbitrary joint chosen at the start. This permits us to ensure that the mean drop in potential per metre, and the mean drop of potential between any two points of the networks shall not exceed the limiting values indicated in paragraphs 13, 14 and 15 of Section B of the Guiding Principles.

It is interesting to know, in order to determine the importance of circulating currents in the earth capable of producing electrolysis, the difference of potential existing between the rails and the earth. In fact, the value of the current density leaving the rails to enter the earth, or leaving the earth to re-enter the rails, is at each point proportional :

To the difference between the potential of the rail and the potential of the earth.

To a certain co-efficient representing the losses of the track with respect to the earth.

Denote by i_M the density at any point M of the current leaving the rails to enter the earth. If at this point the current leaves the earth to re-enter the rails, i_M will be negative.

Let V_M be the potential of the rail at point M and V_{Ms} be the potential of the earth in the neighbourhood of point M, measured with respect to the potential of reference which has already been mentioned.

Let also, C_M be the co-efficient representing the losses of the track at point M per unit length of track.

We have therefore:

$$i_M = C_M (V_M - V_{Ms}) \quad \text{(6a.)}$$

Nevertheless, the variations of potential of the earth along the rails of an electric traction network are always considerably smaller than the variations in potential of the rail itself.

We can thus see that only a small error in the expression for the current density flowing between the rails and the earth is produced when we give the same value V_O to the potential of the earth at all points.

When it is a question of a network of which one of the points is connected to a good earth point we should evidently assume that the potential of this point is exactly equal to the potential V_O.

When, on the contrary, it is a question of a network not having at any point a direct connection to earth, and having well insulated feeders, we can determine the mean value V_O of the potential of the ground from the following considerations:—

We know that in such a case the sum of the currents leaving the rails towards the earth is equal to the sum of the currents returning to the rails—in other words, the algebraic sum of all the currents leaving the rails (or returning to the rails) is zero.

This condition is as follows:—

$$\int C_M (V_M - V_O)\, dl = 0 \quad \text{(7)}$$

The integral being taken over the whole length of the network of rails.

From this we obtain:

$$V_O = \frac{\int C_M V_M\, dl}{\int C_M\, dl} \quad \text{(8)}$$

In connection with the values to be given to the co-efficients of losses C_M, experience has shown that we can assume that these co-efficients keep the same value throughout the whole length of a network if the same type of rail is used throughout, and if the rails are installed throughout in the same way. In such a case the co-efficients are eliminated from formula (8). When this is not the case, it is convenient to divide up the total network into regions within which we can give these co-efficients a uniform value. It is sufficient, however, for the calculation that these co-efficients be determined by an approximately constant factor.

We can, for example, adopt the following values at C:—

$C = 1$ for a total line with grooved rails.

$C = 0{\cdot}7$ for a single track with grooved rails.

$C = 0{\cdot}1$ for a single track with flanged rails

Thanks to these circumstances, we can determine for formula (8) a more complete expression.

Consider the section of track (in the sense defined in the Guiding Principles) or, more precisely, the part of a section of track for which we can give C a uniform value.

Let A and B be the extremities of this part of the section.

L the length of the section.

J the mean value of the total feeder current entering the section.

V_A and V_B, the potential of the points A and B measured with respect to the potential of reference which has already been mentioned.

For this part of the section we obtain integral:—

$$\int_A^B V_M \, dl.$$

But if l is the distance separating the point M from the point A, we have from Ohm's law:

$$V_M = V_A + r \int_A^M \left(I_A + J\frac{l}{L}\right) dl$$

r representing the resistance of the track, I_A the current flowing in the track at the point A (positive in the direction of B towards A).

We have:

$$V_M = V_A + rl\, I_A + r\frac{J}{L}\frac{l^2}{2}.$$

In particular:

$$V_B = V_A + rL\, I_A + r\frac{J}{L}\frac{L^2}{2}.$$

From which:

$$\int_A^B V_M \, dl = L\left(V_A + r\, I_A\frac{L}{2} + r\frac{J}{L}\frac{L^2}{6}\right)$$
$$= \frac{L}{2}(V_A + V_B) - \frac{L^2}{12} rJ.$$

In general, even for a rather long section, the term of the second degree in L is negligible. There remains, therefore:

$$\int_A^B V_M \, dl = \frac{L}{2}(V_A + V_B)$$

and the expression for V_O can be written

$$V_O = \frac{\Sigma\, cL\,(V_A + V_B)}{2\Sigma cL}$$

the summation being extended over all the sections of the traction network.

When the preceding calculations have been made we can form for each point of the network the difference $V_M - V_O$, and make certain that at no point do these differences exceed the value of 0·8 volt indicated in paragraph 12 of Section B of the Guiding Principles.

If this is not so, it signifies that the number of return feeders is too small or that the resistances of these feeders are not efficiently arranged, or, further, that the location of the connection points of the feeders to the rails have not been properly chosen.

It is necessary, then, to study as above the configuration of the feeders or of the rails, satisfying the given conditions.

APPENDIX II.

TO THE GUIDING PRINCIPLES CONCERNING THE MEASURES TO BE TAKEN FOR THE PROTECTION OF CABLES AGAINST ELECTROLYTIC CORROSION.

ELECTRICAL MEASUREMENTS IN CONNECTION WITH ELECTROLYTIC CORROSION.

Electrolytic corrosion being due to stray currents which leave the metallic sheaths of cables, it is desirable to measure directly the intensity of the stray currents in the sheaths themselves or in the earth at the points where these currents enter or leave. There are different methods, of which a number are mentioned below, for carrying out these measurements.

On the other hand, stray currents are caused by differences of potential which exist between the rails and the sheath, the importance of which, other things being equal, is greater, the greater the resistance of the track. Consequently, it is desirable, in order to determine the conditions of a tramway network, to proceed to measure the differences of potential and the drop in voltage, and to measure the resistance of the rail joints.

I.—Measurements of the Stray Current Intensity

A. In the metallic cable sheath,

B. In the earth at the point of entering and leaving the metallic cable sheath.

A. Measurements of the intensity of the stray currents in the cable sheath.

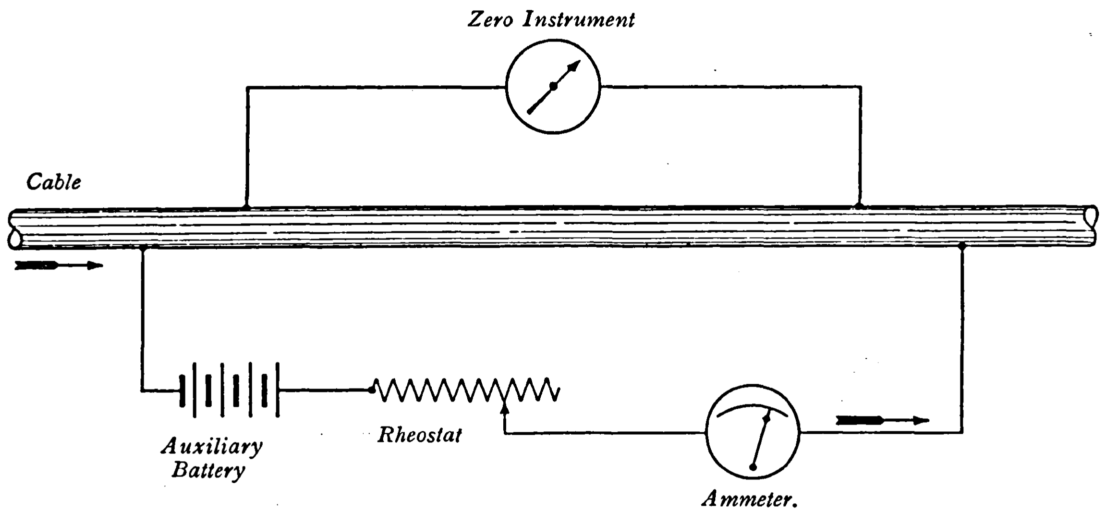
The intensity of the currents which flow in the metallic sheath of a cable can be measured by one of five different methods.

1. The intensity of the stray current flowing in a given length of the sheath can be deduced from the measurement of the difference of potential drop between the two extremities, after having calculated the electric resistance of the given length of sheath from the geometric dimensions and the resistivity of the metal. This method, however, gives rise to error because of the irregularity of the sheath, and because of the damping of the oscillation of the voltmeter shunted by the small resistance of the sheath.

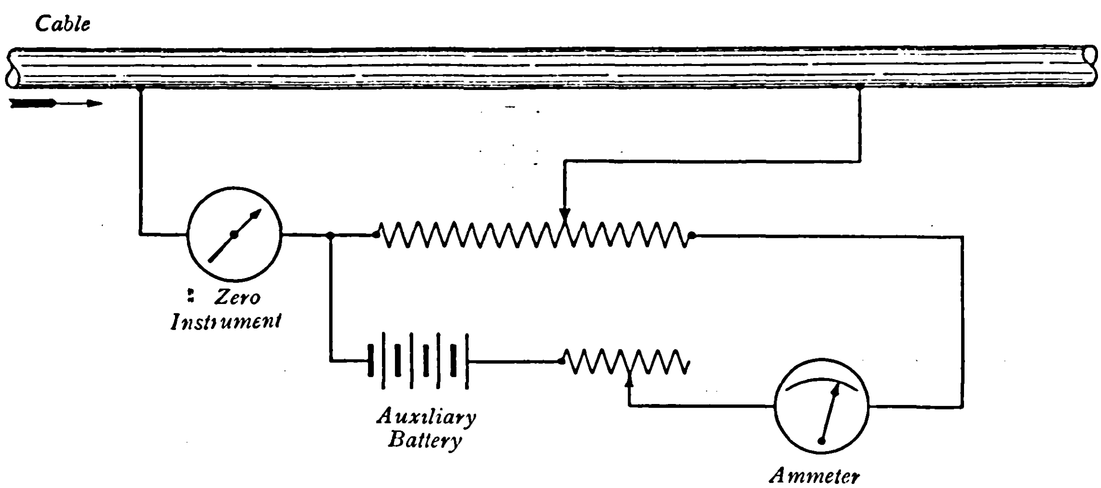
2. In order to measure the stray currents flowing in the metallic sheaths of the cable, this sheath can be interrupted and an ammeter of as small a resistance as possible connected (in practice from 1/100 to 1/10 of an ohm).

3. In order to avoid breaking the continuity of the metallic sheath of the cable, the current which circulates in this sheath can be compensated by means of an auxiliary battery associated with the rheostat and an ammeter. A sensitive measuring instrument with a

short period of oscillation, preferably pivoted (zero instrument), enables it to be determined when this compensation has been properly obtained. The connections are shown below :—

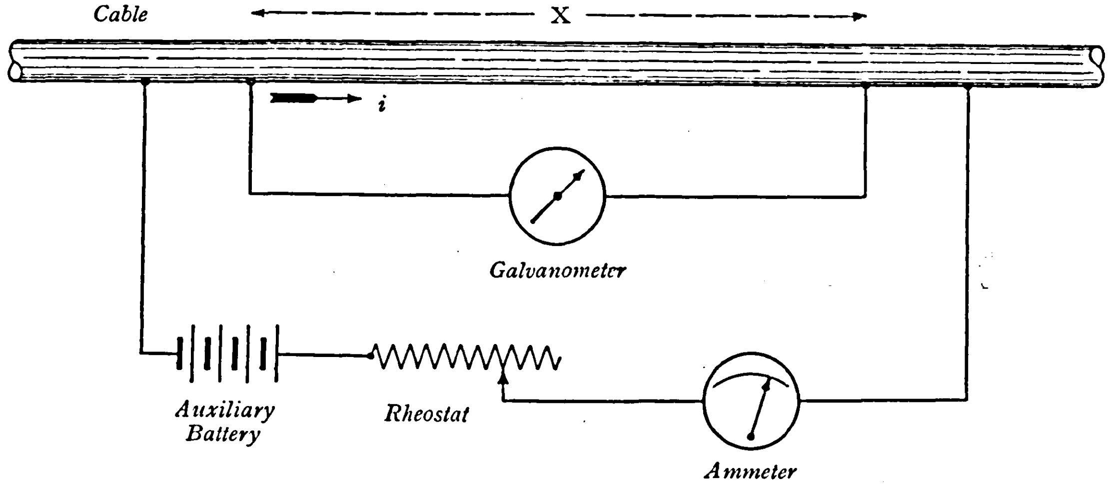


4. Instead of compensating the currents, the voltage along the metallic sheath of the cable can be compensated for according to the following, but it is then necessary to calculate the currents which flow in the sheath, knowing the resistance of the sheath.



5. Finally, the value i of the currents flowing in the cable sheath can be deduced, and the resistance x of the sheath from two successive readings on a galvanometer connected to the two extremities of the sheath. Arrangements of the connections are shown below, and

the theory is as follows. Let i be the intensity of the stray current in the cable sheath at the instant of measurement.



On this current another current i_1 is superposed provided by a battery and measured by an ammeter. The current i_1 is as big as possible and the resistance of the rheostat is so big that the stray current is not shunted appreciably by it. The deflection d is read on the galvanometer. The terminals of the battery are quickly reversed and a new deflection d' is read.

If k denotes a numerical co-efficient depending on the galvanometer, then:

$$(i + i_1) \times X = kd$$
$$(i - i_1) \times X = kd'$$

from which is obtained:

$$i = i_1 \frac{d + d'}{d - d'}$$

$$X = k \frac{d - d'}{2i_1}.$$

B. Measurements of the intensity of stray currents in the earth at the point where they enter or leave the cable sheath.

Experience has shown that a current of 0·75 m.A. per dm^2 of an iron pipe is dangerous from the point of view of corrosion of this pipe. The corresponding value for lead sheaths is in inverse proportion of the electrolytic equivalent of iron and lead. There are three methods for measuring this current.

1. The Haber method, which uses two non-polarisable electrodes of known area buried in the earth at a known distance one from the other and connected to a milliammeter. This method only gives the mean value of the density of the stray currents in the earth, and, besides, the use of these plates alters the distribution of the stray currents in the earth.

2. A method at present being studied in Switzerland uses non-polarisable electrodes of small dimensions placed in a trough of small diameter which has been constructed in the earth near the cable.

This method allows measurements to be obtained for each position of the electrodes in the trough: (1) the current which circulates between them through the earth and (2) the specific resistance of that part of the earth between these electrodes. From this a complete investigation can be made of the stray current paths.

3. Another method used in Germany makes use of a metallic electrode connected to the metallic sheath of the cable by a milliammeter. A cylinder is employed for the electrode having a known surface taken from the sheath identical to that of the cable and filled with tar. After waiting for a short time a measurement of the milliammeter is taken in order to allow the accumulator, consisting of the electrode and the sheath, to discharge.

II.—Measurements of the Differences of Potential and Drop in Voltage.

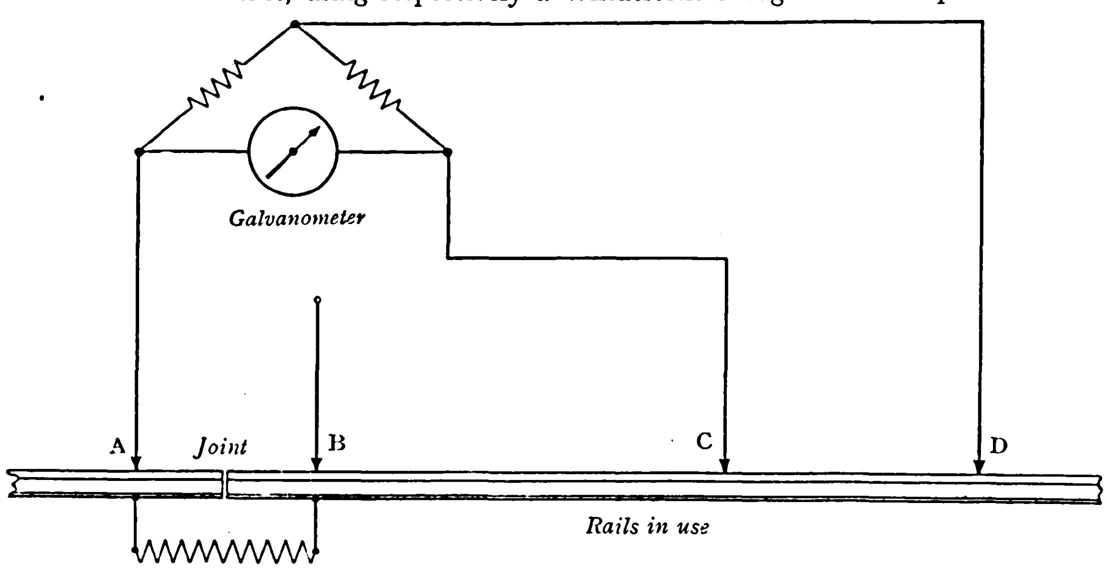
In order to measure the difference of potential between a point of the rail and a point in the metallic sheath of the cable a high resistance milli-voltmeter is used and is connected to two contacts. In order to avoid error due to humidity, these contacts are preferably of the same metal as the objects with which they are in contact. The contacts should be as good as possible and have as small a resistance as possible. It is an advantage for the measuring instrument to have a zero at the centre of the scale; the moving part should have a very small oscillation period.

It is desirable in this measurement to take into account the e.m.f. of the local electrolytic coupling consisting of the two contacts of different metals.

In order to measure the drop in voltage between two points on the rail similar arrangements are used; no correction is required because the contacts are of similar metal. When the two points and the track between which the drop in voltage is to be measured are sufficiently far apart, use is made of pilot wires, which make it necessary to introduce a correction factor to take into account the resistance of these wires.

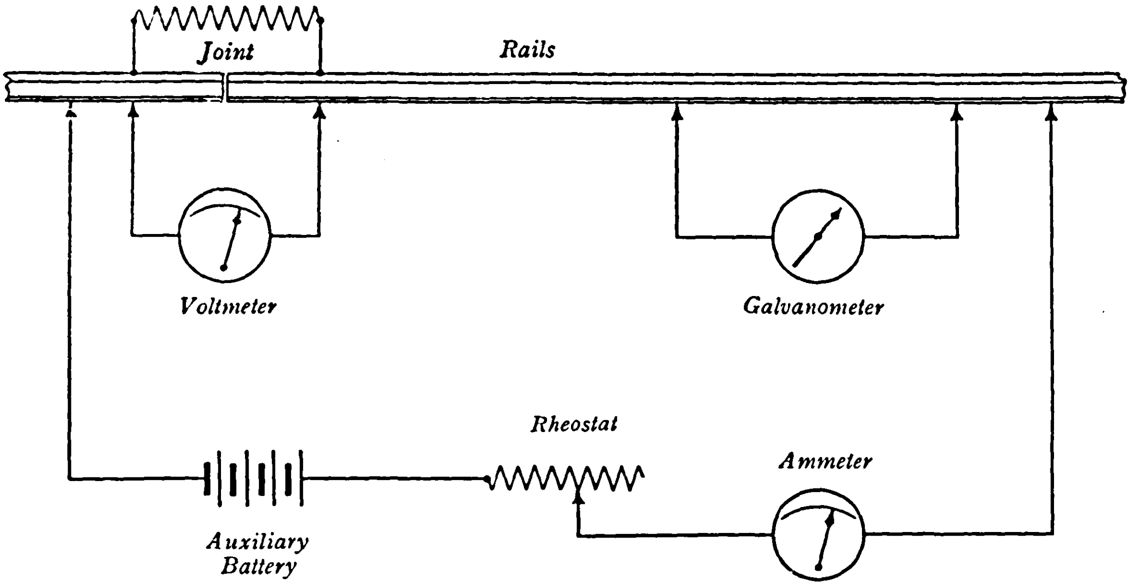
III.—Measurements of the Resistance of Rail Joints.

Two methods exist, using respectively a Wheatstone Bridge and a comparison method.



1. *Wheatstone Bridge method.*—The resistance A-B of the joint is compared by means of the Wheatstone Bridge with the resistance B-C of a certain length of rail. The difference of potential produced between the points B and D by the traction current which flows in the rail serves as a battery; a galvanometer is used as a zero instrument.

2. *Comparison Method.*—The arrangement of this method is as follows :—



The measurement is made when there is no traction current circulating in the rails. An auxiliary battery is used, a rheostat, a voltmeter and a galvanometer. The rheostat is regulated in such a way that the deflection of the galvanometer is constant and well determined. In this case the reading of the voltmeter, in which the scale is calibrated in metres of rails, indicates directly the resistance of the joint in an equivalent length of rail.

PROPOSED GUIDING PRINCIPLES CONCERNING THE MEASURES TO BE TAKEN FOR THE PROTECTION OF CABLES AGAINST CORROSION DUE TO CHEMICAL ACTION.

Definition.—A metal suffers from self-corrosion when its surface corrodes and is covered with a non-adherent product. When the latter has been removed we usually find that the metallic object has lost a part of its weight.

Principal Causes of Chemical Corrosion.

Lead can be attacked by bases as well as by acids. Nevertheless it is one of the most resistant metals from a chemical point of view.

The lead should enter into direct contact, neither with pure cement, nor with water containing lime, nor with alkaline bodies. Cinders are equally dangerous. Chemical corrosion can also be produced in certain soils when there exists organic acids resulting from the decomposition of wood or other vegetable matters. Certain kinds of wood appear to attack the lead; it has been noticed that oak in particular produces corrosion. Sewer water is harmful. Lead does not dissolve in hard water; but soft water, in particular, marsh water containing organic acids, attacks it.

Lead and Alloys.

Telephone cables are contained in lead sheaths of three different types :—

(*a*) Commercially pure lead.

(*b*) An alloy containing 1 to 3 per cent. of tin.

(*c*) An alloy containing 1 per cent. of antimony.

It is not possible at the present time to state which of these three types of cable sheath is the most resistant to chemical corrosion, the data received on this subject being contradictory. However, it is certain that alloys present a superiority as regards mechanical resistance.

Rules Relating to the Installation of Cable Circuits.

(*a*) *Cables in the Earth.*—Unless they are covered with a protective coating or with chemically inert material, lead cables should not be placed directly in the soil.

(*b*) *Cables in Conduits.*—The choice between different kinds of conduits (iron tubes, concrete, sand, stone, wood, etc.) is made principally, chiefly from technical and economic considerations; cables in conduits are usually sufficiently well protected against chemical action from constituents of the soil.

A thick covering of vaseline applied to the surface of the cable sheath at the moment of installation will assist in preventing chemical corrosion.

The conduits should be made as water-tight as possible without incurring unjustifiable expense.

If it is impossible to protect the conduit against infiltration of harmful liquids, it is necessary to place the cables in a sheath which has been covered with a protective layer impregnated with a preservative compound.

All necessary arrangements should be made to guarantee and maintain this layer perfectly water-tight.

A lengthy test has shown that with a well-constructed conduit of concrete of which parts have been sufficiently dried to start with, and provided in the interior with a chemically inert coating, the damage is practically negligible from the point of view of operation and maintenance.

If wood conduits are used, these should be previously impregnated with a preservative substance which does not attack lead.

APPENDIX.

TO THE GUIDING PRINCIPLES CONCERNING THE MEASURES TO BE TAKEN FOR THE PROTECTION OF CABLES AGAINST CORROSION DUE TO CHEMICAL ACTION.

METHOD FOR DETERMINING WHETHER CORROSION IS CHEMICAL OR ELECTROLYTIC.

When placing cables in conduits or in pipes, any direct contact between the sheath and the soil should be avoided, but it is impossible to prevent infiltration of water; this water may come from the surface of the earth and penetrate into the conduits by the inspection holes or at the points where the conduits are connected together; it can evidently contain, in variable quantities, the bodies existing in the neighbouring soil; in any case of corrosion it is necessary to see whether the damage is due to chemical corrosion or to electrolytic action produced by stray currents.

It is certain that considerable assistance would be obtained if each time it were possible to say what was the cause of the damage from the exterior appearance of the corroded sheath. The result of the corrosion, either chemical or electrolytic, varies according to the nature of the material with which the sheath is in contact. When the lead remains exposed for some time to the action of the air or the soil, the products of the corrosion are usually a mixture of lead hydroxide and of lead carbonate similar to commercial white lead. When chemical salts such as chlorides, sulphates and nitrates are found in the neighbourhood of the sheath, the corresponding lead compound will result. These products may result from ordinary corrosion or electrolytic corrosion. The study of the constitution of the products of corrosion does not give by itself a sufficiently precise indication in order to decide on the cause of the corrosion. There is, however, a lead compound of which the presence in the products of corrosion enables it to be stated that the origin is electrolysis due to stray currents. This is lead peroxide (PbO_2). The reddish-brown colour of this compound and its chemical actions are characteristic; it is thus easy to determine its presence, even when it only exists in very small quantities. Nevertheless, if it be true that the presence of lead peroxide can be considered as sufficient index of the electrolysis by stray currents, its absence in certain cases does not show that corrosion is not of electrolytic origin.

Electrolysis by stray currents does not necessarily give rise to the formation of peroxide; and, once formed, this compound is easily decomposed by the contact of organic reducing compound; the electric current which has formed this oxide can, when reversed, destroy it completely.

It is useful to analyse the residue taken from the corroded lead sheaths with a view to determining whether or not they contain peroxide. One of the reagents used for this purpose is formed of a diluted solution of 5 per cent. or more of tetramethyldiaminodiphenylmetane in a 50 per cent. solution of acetic acid.

The salts deposited in the attacked sheath are allowed to fall on a white plate containing a little of the reagents; if in the mass of the liquid clear blue layers are formed, it is an indication that the salts contain lead peroxide. In the case where only very small traces of lead peroxide exist it is necessary to wait 10 to 20 seconds before the precipitate is formed.

It is to be noted that other certain oxiding materials, including the copper compounds, produce the same reaction; but in the case of corrosion to cable sheaths these compounds are not likely to be present.

In Germany, another method is used for finding the cause of corrosion. It consists of a comparison between the quantities of lead chloride existing in the products of corrosion and the proportion of the salt existing in the earth in the neighbourhood of the points attacked. If the products of corrosion contain a greater proportion of lead chlorides than the proportion contained in the earth, it is assumed that this corrosion should be attributed to the passage of an electric current.