C.C.I.T.T.
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RECOMMENDATIONS

for the protection of underground cables against the action of stray currents arising from electric traction systems

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Text approved by the XVIth Plenary Assembly
of the International Telephone Consultative Committee (C.C.I.F.)
(Firenze, 1951)

INTERNATIONAL TELEPHONE CONSULTATIVE COMMITTEE

(C. C. I. F.)

Modifications

brought by the XVIIth Plenary Assembly of the C.C.I.F. (Geneva, October 1954) to the text (Firenze, 1951) of "Recommendations for the protection of underground cables against the action of stray currents arising from electric traction systems"

(Recommendation No. 12, Green Book, Volume II, Geneva 1954, page 30)

THE INTERNATIONAL TELEPHONE CONSULTATIVE COMMITTEE,

Considering

that since the establishment of the "Recommendations for the protection of underground cables against the action of stray currents arising from electric traction systems" (Florence, 1951) as a result of newly acquired information, various corrections must be made to the present text,

Unanimously recommends

that the following modifications should be made to the present text of the "Recommendations for the protection of underground cables against the action of stray currents arising from electric traction systems" (Florence, 1951):

1. Paragraph 1.6.2, sub-paragraph 15, page 5: replace the present text of this sub-paragraph by the following text:

"This method of protection does not impose so severe a limitation of the stray currents (coming from traction networks) as the preceding one; however, the use of this method does not exonerate Organisations operating the traction networks from taking account of the recommendations of Chapter II, relating to the construction and maintenance of those networks; the application of this method of protection is on the other hand facilitated by the putting into practice, on a more or less large scale, of the provisions relative to underground pipes and cables which involve the application of the first method."

2. Paragraph 2.1., sub-paragraph 24, page 7: replace the sentence under *b)* by the following:

"*b)* to facilitate the return of the current through the rails by ensuring low electrical resistance of the track and by judiciously arranging the return system, so as to regularize in particular the potential distribution along the network of rails as far as possible."

3. Paragraph 2.2.3., sub-paragraph 28, page 7: replace the beginning of this sub-paragraph by the following text:

"In particular when these rails are laid on wooden sleepers, the sleepers must be in sound condition and, if they are impregnated, they should not be treated with a product which gives them an appreciable electric conductivity. The ballast must be clean..."

4. Paragraph 2.2.3., sub-paragraph 29, page 7: replace the present text of this sub-paragraph by the following text:

"If the rails are laid on reinforced concrete sleepers, it is necessary to insert an insulating plate between the rail and the sleeper; attention must be paid to ensure that the ballast is sufficiently thick and well maintained, in order to ensure the best possible insulation of the track with respect to earth.

"In addition the bolts fixing the rails to the reinforced concrete sleepers must be very carefully insulated.

"The provisions of sub-paragraph 28 above concerning the ballast must also be applied to tracks laid on reinforced concrete sleepers.

"It is preferable not to use metallic sleepers on D.C. electrified lines. In the case where the use of these sleepers cannot be avoided, attention must be given to ensure that the ballast is sufficiently thick and well maintained because this affords the best possible insulation of the track from earth, this condition being all the more important since a track on metallic sleepers does not normally lend itself to the use of insulating plates between rail and sleeper."

5. Paragraph 2.2.4., sub-paragraph 35, page 8: delete this sub-paragraph.

6. Paragraph 2.5., sub-paragraph 63, page 11:

To take account of certain forms of application of electrical protection, replace in the last phrase "this arrangement is incompatible..." by "this arrangement may be incompatible..."

7. Paragraph 5.3.2.1., sub-paragraph 158, page 22: add the following note at the end of the present sub-paragraph:

"*Note.*—Attention is drawn to the fact that certain metal rectifiers which are subjected to a current which is nearly always in the same direction, can age and thus become conducting to currents in the opposite direction; when an accidental reversal of the current takes place, they do not function and no longer play the part expected of them. This fact must be taken into account when it is proposed to study a system of electrical protection using rectifiers."

RECOMMENDATIONS

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RECOMMENDATIONS FOR THE PROTECTION OF UNDERGROUND CABLES AGAINST THE ACTION OF STRAY CURRENTS ARISING FROM ELECTRIC TRACTION SYSTEMS

FOREWORD

The present recommendations have been drawn up by the International Telephone Consultative Committee in the presence of the representatives of the International Conference of Major Electric Systems (C.I.G.R.E.), the International Union of Producers and Distributors of Electric Energy (U.N.I.P.E.D.E.), the International Union of Railways (U.I.C.), the International Union of the Gas Industry (U.I.G.) and the National Tramways Associations, to facilitate the examination of the proposals for co-existence of underground telecommunication cables and of direct current electric traction lines, from the point of view of the risks of electrolytic corrosion, and, should the necessity arise, for the consideration of what steps should be carried out on the existing installations in order to prevent this corrosion, taking into account the presence of other underground systems.

All questions of an administrative or economic nature, and especially questions of regulations and legislation relating to these problems do not come within the province of the International Telephone Consultative Committee. Therefore, no consideration whatever has been given to the details of the rules of procedure which should be followed in the reciprocal reports of the Administrations and Private Telephone Concerns on one hand, and of the electric traction and other interested services on the other hand.

CHAPTER I

INTRODUCTION

1 1. 1. — The *Recommendations concerning the protection of underground cables against corrosion*, published by the International Telephone Consultative Committee, in 1949, contain general indications relating to the different types of corrosion, their processes, and different methods of remedy.

2 1. 2. — The dangers of electrolytic corrosion of the metallic sheaths of underground cables arise in general from direct current systems; according to the experience acquired to date, it would seem that, except in special cases, alternating currents alone do not produce such effects. Nevertheless, where alternating current is superimposed on direct current the conditions of electrolytic corrosion may be modified.

3 Electrolytic corrosion does not generally appear except in localities where the current leaves the cable to enter the soil.

4 These considerations do not apply in the case of aluminium or aluminium alloy sheaths which are attacked by current of both polarities and also alternating current.

5 1. 3. — The protection of underground plant against electrolytic corrosion includes a large variety of measures; some directed towards the reduction of stray currents, which may not only cause electrolytic corrosion in the neighbouring underground plant, but may also affect the working of certain telephone, telegraph, or signalling systems; others towards the reduction of the magnitude of the corrosion which may be caused by the stray currents which it has not been possible to eliminate.

6 1. 4. — The measures intended to reduce stray currents should be carried out on the electric traction system likely to produce them, and relate to its construction, its running and its maintenance. These are the subject of Chapter II.

7 1. 5. — The reduction of the magnitude of the corrosion is achieved primarily by general measures applied in the arrangement of the cable systems and other underground plant, so as to bring about a reduction of the exchange of current between the earth and the cables or plant. Good construction of cables and plant is essential.

8 These measures must often be completed by further special measures, depending upon the circumstances, intended either to give the maximum protection to the cables against stray current or to reduce the magnitude of the damage which these stray currents may produce. Certain of these measures concern the traction system and the neighbouring underground system of lines at one and the same time.

9 The principle of these various measures is indicated in Chapter III.

10 1. 6. — The conditions of application of these different measures, the object of which has been indicated, may be determined by two different principles.

11 1. 6. 1. — A first method of protection (i.e. protection by limitation of stray current), consists in considering the electric system likely to give rise to stray current, and the system of underground plant which may be damaged, separately

and each independent of the other. The traction system is subjected to rules drawn up with the intention of reducing, as far as possible, the magnitude of the stray current which may leak into the soil in so far as technique and economy allow.

12 On the other hand, various measures which reduce the exchange of current between the underground plant and the soil and so reduce the magnitude of the corrosion are used in so far as technique and economy allow.

13 This method described in Chapter IV, is that which has been in use the longest. It has met with a certain amount of success. However, it has not yet been possible to draw up entirely satisfactory rules, of which the application would be simple and economic in all cases. In view of the necessarily empiric character of the rules given in this chapter they may be, according to certain circumstances, unnecessarily strict, or on the contrary they may still allow certain risks of electrolytic corrosion to persist.

14 1. 6. 2. — A second method of protection (electric protection), the introduction of which is more recent, consists in preventing the harmful action of stray current on underground plant by making the plant the cathode, by measures established on all the systems in the vicinity which may cause stray current and especially the electric traction system.

15 This method of protection does not require a limitation of the stray currents from the traction system as severe as the preceding method ; however, its application is easier proportionally to the amount of reduction in magnitude of the currents ; it is also made easier by the application, to a greater or lesser extent, of measures relating to the lines which the application of the first method requires.

16 However, the application of electric protection is not possible in the case of underground plant made of aluminium or aluminium alloy.

17 Also, if in the region in which electric protection is applied there is any plant made of aluminium, then special steps for its protection must be taken.

18 Electric protection is dealt with in Chapter V.

19 1. 7. — Whichever method is adopted, the measures carried out on the system of underground plant should not be limited to arrangements made only in the localities in which corrosion occurs. Full consideration should be given to the whole of the system and also to other systems ; any measures should be adaptable to any changes made in the conditions of use of the traction system.

20 The efficiency of any protection system can only be guaranteed by frequent, if not continual, inspection of the various installations concerned, so that adjustments can be made with as little delay as possible to take account of any accidental changes in the system which result in important changes in the stray current distribution.

21 The necessity for this inspection is especially important in the case of electric protection.

22 1. 8. — Experience has shown that a cable system may be considered as being protected from corrosion by stray current, if in none of its parts it approaches within a certain distance of the track of a direct current electric traction system or of any works, structures, or conducting pipes metallically connected to the track and in contact with the soil.

23 This minimum distance to be observed in order to remain protected from the danger of corrosion, without special arrangements, is extremely variable ; it depends on the make-up of the soil, the conductance of the track, the type of foundation used, and the respective lengths of the traction and cable systems. In the case of soil of average conductivity this distance is of the order of several hundreds of metres.

CHAPTER II

REDUCTION OF STRAY CURRENT

2. 1. — GENERAL

24 In order to reduce stray current arising from direct current electric traction systems the following should be adhered to :

(*a*) restrict the leakage of current to the earth by ensuring the best possible insulation of the return system (rails, negative feeders and all metallic structures which are permanently connected thereto) ;

(*b*) assist the return of current on the rails by ensuring a low electrical resistance of the track and the judicious disposition of the negative feeders.

2. 2. — THE TRACK

25 2. 2. 1. — The measures concerning the track apply generally whatever the nature of the direct current electric traction system (tramway or railway). They should be applied whatever method is adopted for the protection of the neighbouring cable systems.

26 2. 2. 2. — The rails should be placed on a foundation having low electrical conductivity, placed so as to avoid stagnant water and, if necessary, well dried by hydraulic pumping.

27 2. 2. 3. — So far as a track which is built on an independent foundation is concerned, this condition is fulfilled by the nature of the construction and maintenance of the track.

28 In particular, if the rails are on wooden sleepers, the sleepers should be sound, and the ballast should be clean and well aerated. It is desirable to avoid any contact between the rail and the ballast : this latter should not cover the sleepers, it should be levelled down below the under surface of the rail without making any contact with it.

29 If the rails are on conducting sleepers (metal or reinforced concrete sleepers), care should be taken that the ballast is sufficiently deep, and placed to ensure the best possible insulation of the track from the soil.

30 2. 2. 4. — Special arrangements should be made at such points as level crossings so as to avoid any direct contact between the rails including metalwork connected thereto, and the soil.

31 Whatever type of track is used, it is important as a principle to avoid any contact or any metallic connection between the rails including metalwork connected thereto on the one hand, and all conducting structures in contact with the soil, on the other.

32 It is especially desirable to insulate electrically, those sections of track not energised by direct current from those sections of track which are so energised.

33 On all metallic or reinforced concrete structures it is very necessary to ensure the insulation of the track from the metallic part of the structure. Especially

if the track is built on an independent foundation is it necessary, at the point of passage on to non-ballasted metal bridges, to place the rails on non-conducting material, for example, wooden sleepers or longitudinal bearers, and care must be taken that no fixing parts (long bolts, nuts, ties, clamps, etc.), have any permanent contact with the bridge, nor even a temporary contact at the moment of the passing of a train. It would be wise to make a periodic inspection, for example, once a year, to verify that no contact exists between the rails and the structure, and this special inspection should be made without prejudice to the normal maintenance inspections.

34 However, for the safety of maintenance personnel it may be necessary to make a metallic connection between the rails and a conducting structure; such a case may occur on electric railways at metallic bridges or pylons, and locomotive sheds located in immediate proximity to the track or to the contact rails. It is recommended that consideration should be given to the possibility of making the connection through a device which ensures electrical continuity when required for safety reasons (discharge gap or similar device). Moreover every effort should be made to insulate all external underground cable or pipe systems from the structure.

35 When it is possible, recourse to electric protection may avoid the necessity of taking these precautions.

36 The only metallic connections permissible between the rails and underground pipe or cable systems, are those which are necessary in the application of electric protection to these pipes or cables (see Chapter V).

37 2. 2. 5. — It is advisable that the rails should have a cross-sectional area appropriate to the intensity of the current which they have to carry.

38 In order to reduce the electrical resistance of the track the number of joints must be limited and the electrical resistance of each one of them must be kept sufficiently low. To this end, the practice of welding the rails to each other and to other track equipment is highly recommended in the case of a tramway and is very advantageous in the case of an electric railway.

39 If the rails are not welded together, use should be made of welded rail-to-rail connections, so made that the resistance of the joint does not exceed that of two metres of rail; but in the case of rail-sections longer than 20 metres, the resistance of the joint should not exceed that of a length of rail equal to one tenth of the smaller of the adjacent rails or 5 metres of rail whichever is the less.

40 The use of non-welded rail-to-rail connections is not advised; those used under exceptional circumstances should be specially checked to ensure that their resistance does not exceed that of 5 metres of rail.

41 Unless special precautions in construction ensure the permanent good conductance of the track at places where there are branches, points and crossings, it is necessary to ensure this good conductance by means of special conductors of appropriate cross-sectional area (transverse conductors connected between all the rails on both sides of the branch, points or crossing; longitudinal conductors shunting the electrical discontinuities of the rails).

42 At all places where the track is interrupted and so causes a break in the electrical continuity to the flow of current (swing-bridges, crossings over the track of another network, etc.), the good conductance of the track should be ensured by special conductors, insulated from the earth, connected to the rails on both sides of the broken section.

43 2. 2. 6. — It is advisable as far as possible that there should be equal distribution of current between the rails of a track and of parallel tracks. To this end,

transverse connections correctly spaced and of suitable size, should be provided, except where the requirements of the signalling system in use on the traction system preclude it.

44 2. 2. 7. — In order to maintain the track in the best possible condition from the point of view of electrical conductance, it is desirable to check the resistance of all the rail joints periodically, and to repair them as soon as possible, if the measured resistances are too great.

45 It is desirable to check more frequently the joints at branches and crossings which normally carry current, as well as the joints of the sections of track carrying heavy traffic and those of the track near to the points of connection of the negative feeders to the rails.

46 If the presence of a track circuit signalling system ensures a continuous and exact verification of the sound condition of the track it is not necessary to carry out the periodic inspection of the rail joints.

2. 3. — RETURN FEEDERS AND BUS-BARS

47 2. 3. 1. — The arrangement of the negative feeders of the traction system should be such that if the electrical continuity of a negative feeder or its connection to the rails is interrupted, the rails remain metallically connected to the bus-bars of the sub-stations in service.

48 2. 3. 2. — It is advisable, in order to avoid risks of electrolytic corrosion, that the negative feeders should be insulated from earth throughout their whole length in addition to the bus-bars.

49 This insulation should be checked periodically and in any case whenever an accidental change of conditions of the negative feeders is suspected.

50 If the rails are connected to the negative pole of the generators, it is neccesary to select, wherever possible, for the negative feeding points, localities where the soil is dry, and distant from important duct and cable networks, since it is in the neighbourhood of these points that the danger of electrolytic corrosion is most pronounced.

51 Care should be taken to maintain the connections between the negative feeders and the rails in good condition. In the case of tramways, the welding of these connections is advised.

52 When owing to the layout of the system the negative feeders are not tested directly, it is desirable that arrangements should be made to allow the testing of their good condition (for example, the permanent installation of an ammeter in each negative feeder at the sub-station ; the installation of cut-outs close to the rails in order to permit the measurement of the insulation resistance...).

53 2. 3. 3. — Except where electric protection is applied to the metal sheath of a negative feeder, the sheath should have no direct connection with the rails, the bus-bars or any earth electrode.

54 2. 3. 4. — The recommendation concerning the insulation of the bus-bars may be ignored if a general electric protection scheme is applied to the whole of the network of buried cables and ducts in the region under consideration.

55 2. 3. 5. — In the case of electric traction systems of linear configuration, in which the sub-stations are deployed along the tracks, and more especially in the case of long distance electric railways, it has generally been found necessary, for safety reasons, to make a connection between the metal structure of the sub-station and the rail return circuit.

56 It is then desirable that this connection should be made through a device which only ensures continuity at the moments when safety requires it.

57 Moreover, it is advisable to connect these metal structures to the rails rather than to the bus-bars, unless the potential of the bus-bars is only negligibly different from the potential of the rail.

2. 4. — LIMITATION OF DIFFERENCES IN POTENTIAL

58 2. 4. 1. — It is an established practice to judge the magnitude of the stray current exchanged between a traction system and the earth according to the values of the differences of potential between different points of the rail system [1].

59 The distribution of the potential along a track depends largely upon the configuration of the network, on the conditions of feed [2], on the traffic using the track and finally on the characteristics of the system of negative feeders from the sub-stations. In particular, the distribution of potential can be controlled by modifying the negative feeding points, by regulating the current flow in them (for example, by means of added resistance or by means of automatic voltage control apparatus), by increasing their number and by spreading the load of the system over several feeding sub-stations.

60 2. 4. 2. — In the case of long distance electric railways and more generally of long electric traction systems built on independent tracks, the sub-stations of which are very near the track, it is desirable that the variations in potential throughout the length of the track should be limited ; however, more often than not, the characteristics and the sites of the sub-stations and the return feeders cannot be changed, in which case the variations in potential along the track can only be reduced by keeping the electrical resistance of the track as low as possible.

2. 5. — POLARITY OF THE CONTACT LINE

61 It is sometimes possible to reduce the danger of corrosion by changing the polarity of the contact line. A triple-conductor feed system may also be used, in which certain sections of the contact line are connected to the positive pole, others are connected to the negative pole, and the rails are connected to the neutral point.

62 When the positive pole is connected to the contact line, current leaves the sheaths of the cables or the conduits principally in the neighbourhood of the points of connection of the return feeders, and consequently this is where the greatest risk of electrolytic corrosion lies. When the negative pole is connected to the contact line the maximum points of attack move in accord with the movement of the electric locomotives and the regions of attack are displaced and carried towards the extremities of the feeding areas.

63 Sometimes the periodic reversal of the polarity of the contact line has been made use of to increase the probable life of the underground plant exposed to electrolysis, but this has brought about certain traffic difficulties. Moreover, this arrangement is incompatible with the use of electric protection.

64 The study of each particular case will determine the possibility of adopting one of these arrangements, instead of that generally employed, which consists in connecting the positive pole to the contact line.

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(1) Research is in progress for substituting the use of measurements of differences of potential on the interior of a traction system by more direct measurements of the distribution of current beyond the rails.

(2) With equality of power consumption, the use of a higher feeding voltage reduces the value of the stray currents.

2. 6. — TROLLEY VEHICLES

65 As a general rule, apart from localities where local and intentional earth connections are made, all the parts of the system (contact wires, vehicles, feeders) should be as perfectly insulated from the soil as possible. It is advisable to maintain with care the good condition of this insulation.

66 In the case of a system, the contact wires of which are completely insulated from earth, or which have only one single earth connection on the whole system, the general recommendation as to the maintenance of insulation would appear to be sufficient.

67 The same applies in the case of a system of which the contact wires are completely insulated from earth, and which is divided into sections in different parts, each of which is fed by a sub-station or a group of sub-stations having only one single earth connection.

68 The earth-connections made in the sub-stations only for reasons of safety of personnel or plant, should not be connected to the contact wires except in sub-stations where the contact wire is intentionally earthed. In the case of a system completely insulated from earth, i.e. a system in which a contact wire is not permanently connected with earth, the temporary connection of a contact wire to earth at a sub-station may be permitted so that insulation resistance measurements may be made, but such a connection should only be made for as brief a period as possible in order to reduce the risks of the flow of current to earth in the event of a fault such as the breaking of a conductor or the flash-over of an insulator.

69 In the case of systems making use of a metal track, in use or otherwise by trams, for the return of part of the current, the rail network and the negative feeders should conform to the same conditions as those of a tramway system in active service, allowance being made for the actual running conditions. Especially, when a trolley vehicle line is installed either to replace or to extend a tramway line in service, is it necessary to make a study of the conditions of feed and of return of the currents, in terms of the new situation. The sections of rail which are unnecessary for the return of current should be disconnected, for example by taking up the rails over several metres at least.

2. 7. — PERIODIC INSPECTION PROCEDURE

70 2. 7. 1. — It is necessary to carry out periodical inspection measures on existing traction systems.

71 In particular, the conductivity of the tracks should be regularly tested and the magnitude of the currents in the negative feeders should be checked.

72 2. 7. 2. — It is advisable to make measurements of the average value of the falls in potential along the tracks.

73 An excessive deviation either above or below, in relation to earlier measurements or in relation to the results of calculations made in accordance with Appendix I should be attended to. A very small fall in potential may cause a high leakage of current into the soil. If the fall of potential is too high, this may indicate that the conductivity of the joints is insufficient.

74 2. 7. 3. — In the case of a complicated traction system it is advisable to make measurements of the average values of the differences of potential between the rails and neighbouring parts of the underground pipe or cable system.

75 These measurements are of particular importance where electrolytic action on the neighbouring underground pipes or cables is to be most expected,

(near to the points of connection of the negative feeders, main junction points in the underground system, etc.). If the falls of potential in the complicated underground system are low, and if there are no insulating or high resistance joints on the system, it can be said that the underground cable system is sensibly equipotential. If moreover, it is sufficiently extensive, it can be said that its potential is that of the neutral point of the traction system. These measured values may then be compared with the differences of potential calculated between rail and soil.

76 These measurements may be falsified, notably by the existence of galvanic couples, for, if the voltage is low between the track and the earth, there may at the point of measurement be a difference of potential of the same order between the cable system and the earth as between the track and the cable system.

77 In spite of the assumptions made in arriving at the theoretical value used in the calculation of the differences of potential between the rail and earth carried out as per Appendix I, it is certain that it gives an approximate value of these differences of potential. Thus, the origin of any anomaly between the results of the calculation and of the measurements should be investigated. For example, a difference of potential between the track and the cable system, which is obviously too low, will require attention, and a search should be made for the existence of a chance contact between the rail and the cable system even if the rail foundation is not of conducting material. A too high difference of potential between the track and the cable system is generally the indication of a high resistance in the track, and it is desirable to improve the defective rail joints. In certain cases, particularly bad joints may cause a complete disturbance of the voltage distribution between the track and the cable system.

78 2. 7. 4. — The results of these periodical measurements should be regularly compared with each other in order to draw attention to accidental anomalies and to remedy them quickly.

CHAPTER III

REDUCTION OF THE DAMAGING EFFECTS OF STRAY CURRENT

3. 1. — LAYOUT AND INSTALLATION OF CABLES

79 3. 1. 1. — Cables should be separated as far as possible from electric traction systems; as localities where cables cross the track, and also those where they pass immediately from a great to a short distance from the track, are among the places where the exchange of current with the rail system is to be expected, it is important to reduce their number to the minimum.

80 3. 1. 2. — In considering the layout of cables it must be remembered that the presence of water-courses and the condition of certain kinds of soil favour electrolytic corrosion (moisture content, alkaline substances, salts and acids in solution).

81 3. 1. 3. — In cases where corrosion by stray current is expected, the use in the soil of bare cables having sheaths of lead or of lead alloys should be avoided as a matter of principle. Sometimes however the use of a system of electric protection may modify this recommendation.

82 3. 1. 4. — All metallic contact between the cable sheaths and the conducting fittings or structures connected with the traction system should be avoided, except where specially installed connections for electric protection are concerned.

83 When cables are carried by a metallic bridge or framework which is connected electrically to the traction route, it is particularly necessary to provide special insulation from these conducting bodies, in order to avoid any exchange of current, both under normal conditions and at the time of a short circuit on the traction system.

84 The connections of the sheaths of telecommunication cables to permanent earth connections (other than at exchanges or repeater stations) should be avoided except where they form part of an electric protection system.

3. 2. — CONDUITS, DUCTS, SUBWAYS

85 3. 2. 1. — Cable ducts, jointing chambers, etc., should be constructed so as to avoid contact of the cable sheaths with infiltering or stagnant water. More about this subject will be found in the *Recommendations for the Protection of Cables against Corrosion (Chapter VI).*

86 3. 2. 2. — Each particular case should be considered as to the advisability of bonding together the bare cables in the drawing-in or jointing chambers, at junction points, etc., by means of metallic connections soldered to the sheaths, or wether it is advisable to leave them separated from each other.

87 In cases where it is decided to use bare or lightly insulated cables in metallic ducts (pipes, split metal casings, etc.) good electrical continuity of these ducts should be ensured, except of course, at insulating joints.

3. 3. — INSULATION OF CABLE SHEATHS

88 3. 3. 1. — The complete protection of a cable against electrolytic corrosion is ensured if, by insulating the whole length of the cable from the soil by means of good and durable electric insulation, the exchange of current is practically eliminated.

89 3. 3. 2. — A certain degree of protection is obtained when the total magnitude of current exchanged between the cable and the earth is reduced, without raising to the danger point at certain localities the density of the currents leaving the cable sheath for earth.

90 This result may be achieved by insulating the cable sheath for a sufficient length in the sections where the exchange of current with the soil would be the greatest; especially at the crossings of cables with electric traction lines, over metallic bridges, when laid close to conducting structures in more or less direct contact with the traction rails, at abrupt changes of distance between the cable and the traction rails and in the vicinity of traction feeder stations or points of connection of the negative feeders to the rails.

91 3. 3. 3. — In the zones in which stray currents tend to flow on to the cable sheath, insulation of even a light nature, provided over sufficient length may sometimes suffice : in these zones, insulation of rather poor quality, provided over an insufficient length will have no bad effects.

92 In the zones where the stray currents tend to leave the cable sheath, even a perfect grade of insulation, should it happen to become defective, causes a concentration of current at the defective points, which may result in dangerous corrosion. On the other hand, even in the absence of defects, a perfect insulation, provided over an insufficient length, does not contribute to the reduction of the magnitude of the currents leaving the cable sheath to any noticeable degree, but simply displaces their point of leaving.

93 3. 3. 4. — Insulation of cables may be ensured by means of one of the following :

(1) Insulating covering,

(2) Installation in ducts composed of low conducting material (earthenware, asbestos cement, etc.) having sufficient thickness and constructed so as to be completely impermeable and watertight,

(3) Installation in ducts filled with insulating material,

(4) Installation on insulating supports (pulleys or cleats of porcelain, glass, etc.) in ducts, conduits or subways, constructed so that water and soil may neither penetrate into nor remain in them.

94 Information concerning the specification for insulating coverings is given in the *Recommendations for the Protection of Cables against Corrosion* (Chapter V, pars. 5. 2 and 5. 3). This document especially defines, under the name of coverings of the second category, those which ensure electrical insulation of a very high and durable quality, in the meaning intended by these terms in the present chapter. On the other hand the coverings of the first category should be considered as only giving light insulation.

95 Although the efficacy of coverings of the second category as well as the systems of installation quoted in (3) and (4) may be almost complete even in difficult situations, they may not owing to their high cost, be considered as normal methods of usage, especially if they have to be applied over great lengths.

96 3. 3. 5. — Insulating coverings may always be employed simultaneously with one of the other means mentioned above, or their insulation may be improved by supplementary wrappings or coverings.

97 3. 3. 6. — Electric protection is a good method of maintaining the efficacy of coverings.

3. 4. — ARMOURED CABLES

98 Armouring constructed in accordance with the instructions given in the *Recommendations for the Protection of Cables against Corrosion* (Chapter V, par. 5. 4) protects the insulating covering placed directly on the cable sheath against mechanical damage during and after the installation, and thus ensures a certain durability of its insulating qualities. Often sufficient protection of the cable sheaths against electrolytic corrosion is obtained by the use of cables, armoured over the whole of their length.

99 It is necessary to ensure the electrical continuity of the armouring (except at insulating joints). It is also advisable to connect the armour metallically to the cable sheath at fairly close points (for example at all joints), and to take all steps to avoid the contact of the soil with those sections of the sheath which are bare. When these conditions are fulfilled, the direct exchange of current with the earth is not with the sheath but with the armouring. This latter may undergo corrosion, but this corrosion, since it is only moderate, is not dangerous. If it is desired, the further preservation of the armouring may be ensured by carrying out the more appropriate protection measures, given in the present " Recommendations ".

3. 5. — SECTIONALISING

100 3. 5. 1. — Sectionalising consists of the interruption of the electrical continuity of the system of cable sheaths or pipes, by means of insulating gaps, so as to create independent sections.

101 3. 5. 2. — These insulating gaps should be constructed so that they are mechanically strong and are sufficiently watertight and durable.

102 It is desirable to avoid that their installation should cause any appreciable leakage of current in their vicinity. To this end it is advisable that the insulation of the cable sheath from the earth should be high over the greatest possible length near to the gap ; it is also advisable that these gaps should preferably be installed in localities where they can be kept sufficiently dry.

103 When several cables follow the same route, the insertion of insulating gaps in each one of them should be at the same point on the route ; moreover they should be metallically bonded to one another before and after the insulating gaps.

104 It is recommended that the electrical condition of the insulating gaps and their efficacy should be tested periodically ; to this end, they should be installed so that they are easily accessible, and proper arrangements should be made when installing them, so that they may be brought into service or taken out of service as required.

105 3. 5. 3. — The use of a reduced number of insulating gaps wisely placed, may be useful for the insulation from the rest of the cable system, of certain sections particularly exposed to the exchange of current with the rail system ; such a case would occur especially in the localities where the cable crosses the track, as well as those where it passes abruptly from a short to a great distance from the track.

106 3. 5. 4. — The use of insulating gaps wisely placed and of sufficient number (principally in the zones where the current tends to enter the cable sheath) may,

in certain cases, ensure a useful protection against corrosion, by limiting the magnitude of the exchange of current between the sheaths and the earth, in each of the independent sections.

107 It may be necessary for the sheath to be continuous to alternating current, for example in order to reduce the effects of induction. It is then necessary to shunt the insulating gaps by capacitors or circuits consisting of an inductor and a capacitor in series, the values being chosen to resonate at the most troublesome induced frequency. In the case of a cable having a second inner metallic sheath well insulated from the outer metallic sheath, the latter may be interrupted at regularly spaced intervals.

108 3. 5. 5. — In areas particularly exposed to lightning, the use of insulating gaps is inadvisable, since it impedes the flow of atmospheric discharge currents, which may result in various serious forms of damage to the cables.

3. 6. — ELECTRIC PROTECTION

109 Under the general designation of " electric protection " are included the use of different means for protection against electrolytic corrosion, which are all based on the fact that underground metallic structures (iron, copper, lead, etc., but not aluminium and its alloys) are immunised against corrosion when they are sufficiently electro-negative in relation to the surrounding medium.

110 The various methods of application of electric protection are indicated in Chapter V.

111 Whereas, in certain areas the existence of small defects in the covering of a cable or duct in the presence of stray current may be very damaging owing to the concentration at these points of leakage currents, the application of electric protection removes this danger.

112 Moreover, experience shows that the application of electric protection to a duct or cable with a covering immediately it is laid, may contribute to the preservation of the insulation which the covering affords.

CHAPTER IV

PROTECTION BY LIMITATION OF STRAY CURRENT

4. 1. — ARRANGEMENTS CONCERNING TRACTION SYSTEMS

113 4. 1. 1. — When considering a traction system, in order to verify that the arrangements made to ensure the return of current are satisfactory (notably the number of negative-feeders, the disposition of their points of connection and the distribution of the current between them), it is advisable to calculate the theoretical value of the average differences of potential between the rails and the earth, the highest average difference of potential between points on the system and the average falls in potential along the rails, and these values should be compared with the results of corresponding measurements, as indicated in the earlier paragraphs 2. 7. 2, and 2. 7. 3.

114 The principle of the method of calculation is given in Appendix I.

115 In the present Recommendations the terms *average differences of potential* and *average falls in potential* signify the values obtained by the calculation made for the different sections of route, taking for the power in each section of route the average of all the working days, each day counting as 24 hours, whatever the effective period of service each day may be.

116 4. 1. 2. — The choice of limits to be assigned to the variations of potential in the traction system should be governed by the following points :

(*a*) situation and development of the underground metallic systems ;

(*b*) nature of the track and its foundation ;

(*c*) general layout of the traction system and its conditions of feed.

117 The most precise limits must be adopted in zones where the traction systems cross over underground metallic constructions (water, gas, power cables and telecommunication cables etc.), which are extensive and are relatively dense. In the following, such zones will be indicated by the term *Dense zones*, and the other zones will be termed *Sparse zones.*

118 Also a distinction must be made between the sections of track composed of rails buried level with the soil, and those, which are built on independent foundations, which are thus much better insulated from the earth.

119 In the case of systems, or parts of systems, of linear configuration, the number of ways by which the current is able to return to the sub-stations being more limited than in the case of the complicated systems, it is not possible to adopt such strict limits for the former as for the latter, even in the dense zones.

120 4. 1. 3. — The determination of the average differences of potential between the rails and the earth provides a complete view of the whole traction system, and indicates the zones in which the risks of corrosion of the neighbouring underground systems are the greatest.

121 The calculations are not necessarily absolutely correct owing to the uncertainty presented by the definition of the coefficient of flow itself, which appears in the calculations, and to the fact that the relative values given to the coefficients

of flow for the various sections of route are not always correctly known. But, even if the values of voltage are only calculated approximately, the variations corresponding to a modification of one or several parameters may sometimes be determined with sufficient accuracy. For example, it is possible in this way to compare different methods of balancing and of distribution of the return feeders, when the other parameters (resistivity of the soil, the type of rail, etc...) remain constant.

122 Finally, in spite of the assumptions made in arriving at the theoretical value used in the calculation of the differences of potential between the rails and the earth, it should be recognised that in practice very good results have been obtained in certain countries where, by agreement between the managements of traction systems and the Administrations and Organisations owning underground cable and pipe systems, the following principle has been applied : limitation of the negative values obtained by calculation of the differences in potential between the rails and the earth in those parts of the dense zone other than where the rails are well insulated from the soil (independent foundations, etc). (1)

123 4. 1. 4. — Experience has shown that a limitation of the differences in potential calculated between different points of the rail system will not suffice, in all cases, to ensure that the stray currents arising from this system will be sufficiently low as to cause no risks of electrolytic corrosion, and may, in certain circumstances be needlessly too strict a limitation : the nature of the locality, and certain peculiarities in the method of laying the tracks play a very important part, but may not be taken into consideration in such calculations. Nevertheless, for the moment, as there does not exist an entirely satisfactory criterion for the operation of a traction system from the point of view of the production of stray current, it would seem advisable, to adopt provisionally, limits which have shown themselves reasonable.

124 4. 1. 5. — *In a complicated traction system*, the average difference in potential between any point of the system within the *dense zone* and the nearest sub-station if the substations work in parallel, or otherwise the corresponding feeding sub-station, should not exceed 2.5 volts.

125 *In a traction system of linear configuration, not built on an independent foundation* and fulfilling the conditions of pars. 2. 2. 2 to 2. 2. 7, the average difference in potential between any point of the system within the *dense zone*, and the nearest sub-station, should not exceed 2.5 volts, if the distance in a straight line between these two points is lower than 1.66 kms. For two points whose distance apart in a straight line is greater, the value expressed in volts of this difference of potential, should not exceed 1.5 times the value of the distance in kilometres.

126 *In a traction system of linear configuration not built on an independent foundation*, and fulfilling conditions of pars. 2. 2. 2 to 2. 2. 7, the average difference in potential between any point of the system within the *sparse zone*, and the nearest sub-station should not exceed 2.5 volts, if the distance in a straight line between these two points is less than 1.25 kms. For two points whose distance apart in a straight line is greater, the value expressed in volts of this difference in potential should not exceed twice the value of the distance expressed in kilometres.

127 In the cases of traction systems of linear configuration, set up on an independent foundation, and fulfilling conditions of pars. 2. 2. 2 to 2. 2. 7, there is no need to fix a limit for the difference in potential (see par. 2. 4. 2).

128 4. 1. 6. — If certain traction networks have been constructed following more strict rules than those of paragraph 4. 1. 5, and if the application of these rules

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(1) The Swiss rules limit these negative values to 0.8 volts.

has proved satisfactory both technically and economically for all the services interested, there is no need to adopt the limits indicated in paragraph 4. 1. 5.

129 If, on the contrary, it is established that owing to the particular characteristics of an existing traction network values markedly higher than the limits given in paragraph 4. 1. 5 may be permitted without damage to the neighbouring ducts and cables, these values may be retained, instead of the limits.

130 4. 1. 7. — The arrangements made in order to ensure the return of the traction currents should be such that the value of the current flowing in the rails is limited, which corresponds to a limitation of the average fall in potential.

131 4. 1. 8. — Finally, when one establishes the equipotentiality of the points of connection of the return feeders, the maximum difference of potential on the interior of the network is the smallest possible for the given conditions of feed and for a fixed position of these points of connection : however it is only important to establish this equipotentiality if it leads to an improvement of the situation from the point of view of the magnitude or the distribution of stray currents.

4. 2. — ARRANGEMENTS CONCERNING UNDERGROUND CABLE SYSTEMS

132 Even if an electric traction system satisfies the different conditions given in the foregoing paragraphs, and is properly maintained, the underground pipes and cables placed in the vicinity of this system are not entirely protected from the risk of electrolytic corrosion.

133 In order to provide against these risks it is desirable to make the general arrangements indicated in Chapter III concerning the layout and the fixing of cables, and also the construction of ducts or conduits, the type of coverings, or the armouring of cables.

134 If there is any occasion to doubt the sufficiency of these steps, particularly at certain parts of the cable network, they may be completed by applying certain of the special arrangements described in Chapter III (pars. 3. 3. 4 and 3. 5), within the necessary limits, and in so far as economy allows.

CHAPTER V

ELECTRIC PROTECTION

5. 1. — GENERAL

135 5. 1. 1. — Electric protection of cable sheaths and of metal ducts, (iron' copper, lead..., but not aluminium and its alloys), has for its object their protection against corrosion by keeping them electro-negative (or cathodic) with respect to the surrounding electrolytic medium (soil, water,...).

136 To obtain this result, it is necessary to create a protective field of direct currents in the surrounding medium, which, entering the duct or the cable sheath at each of the points where they are in contact with this medium, flow along their length, and are collected at certain points by metallic connections (called drainage connections or drainage bonds) and are returned into the medium by means of underground or buried anodes, or via a rail network acting as an anode.

137 According to the case, these protection currents are produced by a direct current generator, or otherwise simply originate from the tracks of an electric traction system to which the metallic ducts requiring protection are connected at proper points by suitable devices.

138 5. 1. 2. — These protection currents superimpose themselves on the pre-existing stray currents.

139 In order that the electric protection may be effective, it is necessary that at all points on the duct or cable sheath, the resultant of the stray currents and the protection current shall tend to enter the duct or sheath, and that the resulting potential shall be sufficiently electro-negative with respect to that of the surrounding medium to render the metal passive and corrosion impossible (see Appendix IV § A. 4. 1).

140 5. 1. 3. — This result is obtained by means of protection currents the value of which is smaller the higher the conductance of the cables or ducts to be protected and the higher their average insulation resistance from the surrounding medium.

141 5. 1. 4. — If small protection currents are satisfactory, the electric field resulting in the surrounding medium is less important and it is easier to avoid damaging repercussions on other underground structures in the neighbourhood of the cables or ducts being protected.

5. 2. — GENERAL CONDITIONS OF INSTALLATION

142 5. 2. 1. — The establishment of electric protection requires the examination of the whole of the electrical and topographical situation of the traction network and of the network of cables and ducts to be protected, taking into account, when necessary, the presence of all the other underground ducts or metallic structures in the area. This situation should be reconsidered whenever an important change in the existing conditions occur. General indications on the manner of carrying out this preliminary study are given in Appendix IV.

143 5. 2. 2. — In order that the currents, taken up along their length by the metal ducts or cable sheaths to be protected, may reach the drainage connections, it is necessary that these ducts or cables should have no breaks in their electrical continuity, unless they are intentionally divided into sections, each having its proper drainage connections.

144 With the exception of separation points between such sections, or again of certain special points where an intentional increase of the resistance is part of the arrangements adopted for electric protection, (see, for example, par. 5. 3. 3), it is absolutely necessary to eliminate or to short-circuit insulating or high resistance joints, so that the longitudinal conductance of the duct or cable sheath is the best which can possibly be obtained.

145 5. 2. 3. — It is necessary to avoid any proximity or any direct metallic contact between the cable or duct being protected and any external metallic structure or ducts which are not part of the protection scheme.

146 When an electrically protected duct or cable is fixed to a metal bridge, it is necessary, especially if a duct or cable sheath of low linear resistance is concerned, either to insulate it carefully from the bridge, or to separate the section fixed to the bridge from the rest of the duct or cable by means of resistance joints, shunting it by insulated conductors of a correct size.

147 The same applies if a section of duct or cable is erected on metal structures (pylons, frames) not insulated from the earth.

148 5. 2. 4. — The drainage connections and their attachments to the cable or ducts being protected, should be well insulated from the earth.

149 5. 2. 5. — In the case of protection against stray current due to an electric traction network, the establishment of efficient electric protection is only possible if the tracks and the return feeders are constructed and maintained in good condition, as indicated in Chapter II of the present Recommendations.

150 This establishment is simplified in proportion to the low-magnitude of the differences of potential which may be found on the track network. Nevertheless, according to the conditions of establishment of electric protection, it is possible to dispense with the limits given in Chapter IV, relating to protection by limitation of stray current.

151 5. 2. 6. — Any system of electric protection requires an effective inspection of both the general conditions of working, and the good condition of the apparatus installed. This inspection includes mainly a frequent checking of the magnitude of the protection currents and a periodical testing of potentials along the ducts or cables protected. In order to carry out these operations with ease, it is desirable to install accessible test points at places chosen for convenience.

152 5. 2. 7. — If, in order to protect the apparatus inserted in the drainage connections, or to prevent the passage of an excessive current through the ducts or cables being protected in case of a railway accident, automatic cut-out devices (fuses, cut-outs etc.) are installed in the connections, it is necessary to provide an immediate alarm system to draw attention to the failure of the drainage connection, thus making the arrangement safe.

5. 3. — METHODS OF INSTALLATION OF ELECTRIC PROTECTION

153 Electric protection is carried out according to the following methods, which may be installed singly or simultaneously.

5. 3. 1. *Direct electric drainage*

154 5. 3. 1. 1. — Direct electric drainage consists in connecting the cable sheath or the duct to be protected, by metallic drainage connections either to the rails, or to the return feeders, or to the negative bus-bars of the traction system.

155 Direct electric drainage may only be made if it is ensured that, whatever the running conditions of the traction system may be, there will be no reversal of the direction of the current in the drainage connections (except very rare reversals of short duration and of low current value); therefore, it cannot be employed in all circumstances.

156 Preferably the drainage connection is made to the negative bus-bar of the sub-station from which the traction current originates or exceptionally, to a point on a return feeder. The connection may not be made directly to the rail unless it is ensured that the said rail is always electro-negative in relation to the earth at the point chosen.

157 5. 3. 1. 2. — In order to avoid a needless increase of the voltages and currents involved, it is sometimes useful to insert resistances of suitable value in certain drainage connections : it is advantageous to use resistances the value of which increases as the current increases.

5. 3. 2. *Polarised Electric Drainage*

158 5. 3. 2. 1. — Polarised electric drainage consists of inserting in certain selected drainage connections, apparatus which restricts the flow of current to one direction only (a contactor controlled by a polarised relay, a rectifier, etc...).

159 This arrangement allows the choice of the points of connection of the drainage connections with greater freedom than in the case of direct drainage, since it is no longer necessary that these points should always be electro-negative with respect to the earth. The action of one or other drainage connection is eliminated during periods in which direct connection would be harmful. This circumstance being taken into account, the complete study which should be undertaken for the judicious choice of the points of connection and the determination of the characteristics of the equipment, generally leads to the simultaneous installation of several devices distributed along the cable or duct to be protected.

160 5. 3. 2. 2. — Since any connections which may be made between the cables and ducts themselves are all part of the same system of protection, they should include a unidirectional device, if it is necessary that the current flowing in them should be unidirectional.

5. 3. 3. *Controlled Electric Drainage*

161 5. 3. 3. 1. — This system consists of controlling the currents flowing in the ducts or cable sheaths so that the potentials of their different sections differ from those of the neighbouring parts of the soil by a voltage which is just sufficient to obtain the desired protection, by means of the provision of a sufficient number of drainage connections having suitable resistances and the insertion of resistance joints (insulating gaps shunted by resistance) in the ducts or cables to be protected.

162 5. 3. 3. 2. — The resistances placed in the drainage connections should be adjustable so that their value may be adapted fairly closely to the changes in conditions of the system.

163 5. 3. 3. 3. — Inspection of the working of the system should be permanent.

5. 3. 4. *Forced Electric Drainage*

164 5. 3. 4. 1. — Forced electric drainage consists of connecting the cable sheath or the duct to be protected, by drainage connections to the negative terminal of

a direct current electric generator, the positive terminal of which is connected to the rail of the traction network.

165 This device functions even when the potential of the rail at the connection point is initially higher than that of the duct.

166 It allows the use of the excellent anode constituted by a well maintained rail system; it is, in a way, a device intermediate between polarised electric drainage and cathodic protection using a sacrificial anode (see par. 5. 3. 5).

167 The electromotive force of the generator is in parallel with that resulting from the difference of potential, of varying direction and value, which exists between the rails and the duct being protected; the generator should thus at certain times overcome the reversals due to this variable difference of potential; its working characteristics (volts, amperes) should consequently take local conditions into account.

168 In certain cases, the low slope characteristic of a normal rectifier is satisfactory; in other cases a special characteristic is necessary (obtained, for example, by the insertion of an inductance in series with the rectifier in the secondary of the transformer feeding the rectifier).

169 5. 3. 4. 2. — Since the alternating currents flowing in the lead sheaths of certain cables are likely to damage the rectifier of the forced drainage apparatus, it may be necessary to provide a protection device (for example, a series inductance) in the forced drainage circuit.

170 5. 3. 4. 3. — In the case where the protection current is derived from rectifiers having high harmonic content, and disturbance may be caused to the circuits of the protected cable, it is usual to insert an appropriate filter network in the drainage connexion.

5. 3. 5. *Cathodic protection with a sacrificial anode*

171 5. 3. 5. 1. — Cathodic protection with a sacrificial anode consists of connecting by means of a metallic connection, the cable sheath or the duct being protected to the negative terminal of a direct current generator; the positive terminal is connected to a mass of metal buried in the ground which serves as an anode (sacrificial anode) by a connection which, as well as its point of connection to the anode, should be well insulated from the earth in order to avoid the possibility of very rapid corrosion, brought about by a high concentration of current at this point, causing a breakdown of the protective system.

172 It is advisable to separate the anode sufficiently from the cable and from the duct being protected in order to increase its effective zone of action.

173 5. 3. 5. 2. — The magnitude of the protection current depends principally upon the electromotive force of the generator and the resistance of the circuit, formed by the earth, the sacrificial anode, the duct or the cable in question, and the connections between them. The resistance of the anode is nearly always greater than the rest of the circuit, hence the importance of installing this anode with care, in order to obtain as low a resistance as possible (about 1 ohm). A preliminary examination of the site (electrical prospecting) often leads to the selection of a situation favourable in this respect. The soil immediately surrounding an anode may be further improved by means of a suitable backfill (bentonite, gypsum).

174 In spite of these precautions it may happen that after a certain time the resistance of the anode, after having temporarily decreased, increases progressively, since the products of its inevitable corrosion are bad conductors and are not soluble. It is therefore advisable to inspect the anode periodically, with a view to improving or replacing it when it's resistance has become too high.

175 5. 3. 5. 3. — Moreover, the position of each anode should be selected beyond the sphere of influence of any other underground metallic structure likely to be placed in danger.

176 5. 3. 5. 4. — The recommendation made in par. 5. 3. 4. 3. also applies in the case of cathodic protection using buried anodes.

5. 4. — PRESERVATION OF NEARBY STRUCTURES

177 5. 4. 1. — When several metallic ducts or sheaths of underground cables are parallel over a long distance in an area traversed by stray current arising from a traction network, it is often useful to extend the electric protection to all the ducts or to all the cable sheaths.

178 5. 4. 2. — When high and low voltage cables and telecommunication cables are included in the same protection system their sheaths are electrically connected.

179 This connection is established naturally when in an electric traction sub-station all the earths are connected to the negative bus-bar and when also there exists a drainage connection between the telecommunication cables and the bus-bar.

180 When local conditions require the interconnection of the cable sheaths at a point remote from the electric traction sub-station, it is sometimes desirable for purposes of cathodic protection to isolate from earth the cable sheaths at certain high or low voltage sub-stations, provided appropriate measures can be taken to safeguard the telecommunication cables in the event of break down on the high or low voltage installations.

181 When this is done, connection between the cable sheaths is generally established through a resistance, inductance or other appropriate device ; it is necessary to take precautions in case of accident to the high or low voltage cables to limit the current in the sheaths of the telecommunication cables so that no damage to the equipment or disturbance to the telecommunication network will result.

182 5. 4. 3. — In the case of a short parallel length, or a convergence, or a cross-over of routes, it is advisable to consider which of the following solutions is the most advantageous :

(*a*) extension of the protection to all the ducts or cable sheaths present and arranging for suitable sectionalising of particular ducts or sheaths ;

(*b*) provide protection of the protected ducts or cable sheaths so that, in the zone of convergence no risks are incurred by the non-protected ducts or cables.

183 For example, when an electrically protected duct passes along a route in which there are numerous non-drained underground cables, it may be preferable in certain cases, rather than to extend electric protection to these cables by connecting their sheaths to the protected duct by means of protection connections, to have recourse to one of the following arrangements :

— improving the insulation of the protected ducts or cable sheaths in the zone of convergence ;

— separating, from the whole of the electrically protected duct or cable sheath, the section situated in the zone of convergence, by means of resistance joints, and shunting this section by insulated conductors of a suitable size.

184 In effect when there is, in this zone, a natural entry of stray current into the cable sheaths, the only risks of electrolytic corrosion of these sheaths, at this point, arises from too large protection currents in the duct. If, to eliminate these risks, the whole of these sheaths, (which generally constitute a good local earth connection), were connected to the duct, the potential of the duct being protected would be needlessly raised necessitating the augmenting of the protection installation, and possibly of making new drainage or forced drainage connections.

APPENDIX 1

PRINCIPLE OF CALCULATION

OF THE DISTRIBUTION OF THE VOLTAGES IN THE RAIL NETWORK OF A TRACTION SYSTEM

IDEAS ON DIFFERENCE BETWEEN THE POTENTIAL OF THE RAILS AND THE CONVENTIONAL POTENTIAL OF THE EARTH

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185 For consideration of the measures to be carried out in order to reduce the intensity of stray current arising from traction systems, it is desirable to know, at least approximately, the distribution of the voltage in the rail system; it may be equally desirable to determine the influence of the disposition of the return feeders on this distribution. Finally, it is useful to discover, at least roughly, the zones in which the current leaves the rails and enters the soil, and those in which the current returns to the rails.

186 Further, in certain countries, according to theories which will be indicated hereafter, a certain value of potential is defined as being the conventional potential of the soil and of the underground systems, and effort is made to limit the differences between the potentials of the rails and this conventional potential.

187 The object of this appendix is to indicate on which hypotheses these different calculations may be based, and to show the principle of the method which enables these calculations to be carried out.

A. 1. 1. — DISTRIBUTION OF VOLTAGES IN THE RAIL SYSTEM

188 Since the effects of electrolysis depend not on instantaneous values of currents but on their integral with respect to time, it is justifiable to calculate either the integrals with respect to time of the currents or the voltages or—which amounts to the same thing—the average values of these magnitudes with respect to time.

189 In the *Recommendations* (chapter IV, paragraph 4. 1. 1) it was agreed to consider as average values, those which relate to the total of a large number of working days, each of these days counting as twenty-four hours, whatever may be the actual duration of service in a day.

190 The calculations are made using, for simplification, the following hypotheses.

191 (a) *The losses of current along the rails or the return feeders, are negligible.* This hypothesis is the better satisfied as the system is well constructed and maintained : moreover, in adopting it, values are obtained near to, but exceeding, the fall of potential along the length of the rails.

192 (b) *The average value of the current fed into the rails via the locomotives, per unit length of the track, remains at a uniform value at all points of any one section of route.* (The term *section of route* denotes any continuous portion of route where no crossings, no junctions and no return feeder connections are made).

193 This value may, when it concerns a route in use, be deduced from the readings of the meters installed in the vehicles. If it concerns a projected route, it may be deduced from the empirical relationships giving the specific load of the machines as a function of the weights carried, of the speed of running, of the gradient of the line, etc.

194 The other data of the problem are the general configuration of the rail system, and of the return feeders, and the value of the resistances of these various elements of the system.

195 The calculations may be carried out as follows :

196 1. At each point of the rail system the average value of the feed current is known. I, the total current entering the whole of the system may be determined.

197 The currènts entering the rail system can only leave it by the return feeders ; therefore, the sum of the currents leaving by these return feeders is equal to I.

198 2. When there is a single return feeder F_1 having a known position, and if at each point of the route, the value of the entering current and also the value I_{F1} of the current leaving by the return feeder (a value equal to I in this particular case) are known, by application of the laws of Kirchoff and Ohm it is possible to determine, on one hand the value of the voltage at each point of the route, and on the other hand the value of the fall in potential along the rails.

199 This result may be obtained either by numerical calculation, or graphical equations, or by electrical measurements on a model.

M being any point of the rail system, it is assumed that

I_{M1} is the average value of current flowing past this point M,

V_{M1} is the value of the average voltage between the route at this point and a reference point chosen at will, in the system.

(The second indices 1 mean that I_{M1} and V_{M1} have been calculated allowing that the whole of the current I has been carried away by the feeder F_1).

200 3. Now, taking the case of a system comprising p return feeders $F_1, F_2 \ldots F_p$ the positions of which are known, the preceding calculations may be repeated for each return feeder, supposing that it is the only one.

Thus,

$I_{M1}, I_{M2}, \ldots I_{Mi}, \ldots I_{Mp}$, the different values of current which would flow at one single point M in the rail system ;

$V_{M1}, V_{M2}, \ldots V_{Mi}, \ldots V_{Mp}$, the different values of the voltage between a single point M and a point chosen at will, but the same in all cases, each calculated on the theory of the existence of one single return feeder.

201 It is important to note that these quantities may be calculated once and for all, from the values of entering current, and from the positions of the feeders, independently of any other electrical characteristics of the feeders.

202 Finally let : $I_{F1}, I_{F2}, \ldots I_{Fi}, \ldots I_{Fp}$, be the values of the currents leaving respectively by the feeders $F_1, F_2, \ldots F_i, \ldots F_p$.

203 Then

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

204 The value of the current at point M will be :

$$I_M = \frac{\sum_{i=1}^{i=p} I_{Fi}\, I_{Mi}}{\sum_{i=1}^{i=p} I_{Fi}} \qquad (2)$$

205 The value of the voltage at point M will be, in the same way :

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

206 Thus, in the theories elaborated up to the present, the knowledge of the values of the currents leaving by each feeder would allow the complete determination of the distribution of currents in the rail system, as well as the distribution of voltages.

207 4. For the application of these formulae, different data may be assumed according to the object of the study.

208 4. 1. — For example, one may stipulate " a priori " the value of the current which should leave the rails by each return feeder. In order to obtain this result effectively it is necessary to determine the electrical characteristics of the feeders, so that they may fulfil certain conditions.

209 Let R_1, R_2, ... R_i, ... R_k, ... R_p be the resistances to be given to each of these feeders.

Let V_1, V_2, ... V_1 ... V_k ... V_p be the values of the voltages between the points *1*, *2*, ... *i*, ... *k*, ... *p*, where these feeders are connected to the rails, and the point of reference.

210 According to the general equation (3), the expression of these values is :

$$(4) \qquad \left[\begin{array}{l} V_1 = \dfrac{\sum\limits_{i=1}^{i=p} I_{Fi}\, V_{1i}}{\sum\limits_{i=1}^{i=p} I_{Fi}} \\[2em] V_k = \dfrac{\sum\limits_{i=1}^{i=p} I_{Fi}\, V_{ki}}{\sum\limits_{i=1}^{i=p} I_{Fi}} \end{array} \right.$$

211 Since all the return feeders are connected to the same bus-bar at the generating station, it follows :

$$(5) \qquad V_1 - R_1\, I_{Fi} = \ldots = V_k - R_k\, I_{Fk} = \ldots = V_p - R_p\, I_{Fp}.$$

212 The whole of the p equations (4) and the $(p - 1)$ equations (5) would not suffice to determine the $2p$ unknowns (values of V_k, and values of R_k). The value of one of these unknowns may be fixed at will, therefore.

213 It is necessary to remember however, so that the analytical result should have a physical meaning, that the values found for the different resistances should be positive.

214 4. 2. — It may also be proposed to determine the distribution of return currents in the different feeders, so that the points where all the feeders are connected to the rails should be at the same potential.

215 The system of equations to be resolved thus comprises :

the relation (1)
the p equations (4),
to which must be added the $(p - 1)$ equations (6) :

$$(6) \qquad V_1 = V_2 = \ldots = V_k = \ldots = V_p$$

or, altogether, $2p$ equations to calculate $2p$ unknowns (values of I_{Fk} and of V_k). The result of this problem is thus completely determined.

216 4. 3. — It may be proposed to discover what is the distribution of currents in a rail system, when the return feeders have a defined resistance in advance.

217 Again let V_k be the value of the voltage between the point of connection of the feeder F_k and the point of reference, and let R_k be the resistance of this feeder.

218 The system of equations to be resolved then includes,

the relation (1),
the p equations (4),
the $(p - 1)$ equations (5)

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

219 5. Whatever the result may be, when the values of the currents leaving by each feeder are determined, it is possible by means of the equations (3), to calculate the distribution of potential along the rails, the potential of reference being that of a point chosen at will at the beginning. This ensures that the average potential drop per metre, and the average differences in voltage between any two points of the system, do not exceed the limiting values.

A. 1. 2. — IDEAS ON THE DIFFERENCE BETWEEN THE POTENTIAL OF THE RAILS AND THE CONVENTIONAL POTENTIAL OF THE EARTH

220 It is possible to determine in a rough manner the zones in which the current leaves the rails and enters the earth, and those in which the current returns to the rails, on the basis of the following theory :

221 Let i_M be the current, at any point M on the rails, leaving the rails and entering the earth (if, at the point considered, there is a return of current into the rails, i_M is negative) ;

V_M is the value, calculated earlier, of the voltage between the point M and a reference point, chosen at will ;

V_o is the value of the voltage between a point in the earth infinitely distant from the traction system, and the same point of reference.

222 It is admitted that it is possible to write at each point :

$$(7) \qquad i_M = C_M \, (V_M - V_o),$$

C_M being a coefficient of the nature of a conductance called the *coefficient of flow* at the point M, and principally depending at each locality on the nature of the rails, the manner of their mounting, and of the electrical qualities of the neighbouring conductive surroundings (foundations and ground).

223 By means of this theory, and supposing the values of C_M to be known along the whole length of the route, it is possible to calculate V_o when it concerns a traction system, of which the feeders are perfectly insulated from the earth, especially at the generating stations.

224 In this case, in effect, the sum of the currents leaving the rails into the earth is equal to the sum of the currents which return to the rails. In other words, the algebraic sum of all the exchanges of current between the rails and the earth is nil.

225 Thus :

$$\int C_M \ (V_M - V_o) \ dl = 0, \tag{8}$$

the integral being extended along the whole length of the rails :
it follows

$$V_o = \frac{\int C_M \, V_M \, dl}{\int C_M \, dl} \ . \tag{9}$$

The knowledge of V_o then allows, by application of the relation (7), the determination of the zones of entry or of emergence of current.

226 It is useful to note that for the application of the formula (9), it is not necessary to know the absolute values of C_M but that it is enough to know their ratios to one of them. Particularly, if C_M were constant for all the points of the system, the relation (9) would become

$$V_o = \frac{\int V_M \, dl}{\int dl} \tag{9B}$$

227 Experience seems to show that this theory of calculation gives results which are sufficiently accurate for the object of the investigation, when it concerns a system composed of rails of a uniform type, set up everywhere in the same manner, and when the foundation of the track presents no anomalies anywhere in conductivity.

228 Furthermore, it has been shown by the experience of certain countries that if the foundation of the track nowhere presents any anomalies in conductivity, the calculations lead to sufficiently accurate results for the object of the investigation, when relative uniform values of the coefficient of flow are adopted for sections of track in which use is made of the same type of rails mounted in the same manner.

229 Here, for example, are some of these relative values :

$C = 1$ for a double track with grooved rails ;

$C = 0.7$ for a single track with grooved rails ;

$C = 0.1$ for a single track with Vignole rails.

230 Because of this, a more developed expression may be given to the formula (8).

231 Given a section of track or more exactly a part of a section of track for which a uniform value may be attributed to C, then :

A & B are the extremities of this part of the section,
L = length of this part,
J = the average value of the total feed current entering the section,
V_A and V_B the voltages between points A & B and the point of reference as previously given.

232 For this part of the section, the integral is :

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

233 where l is the distance of the point M from the point A.

From Ohm's law :

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

r representing the resistance of the track per unit of length,
I_A the current flowing along the track at point A, taken positively in the direction B to A.

Then,
$$V_M = V_A + rlI_A + r\frac{J}{L}\frac{l^2}{2}$$

In particular
$$V_B = V_A + rLI_A + r\frac{J}{L}\frac{L^2}{2}$$

Whence

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

234 In general, even for a somewhat long section, the term of the second degree in L is negligible. It remains then :

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

And the expression V_o may be written :

$$V_o = \frac{\sum CL\,(V_A + V_B)}{2\sum CL}.$$

the sum being extended to all sections of the traction system.

V_o is the conventional potential of the whole of the soil and underground system (mentioned above) with respect to the arbitrary point chosen as the reference point.

235 It is desirable to note that if imperfect knowledge of the values of C leads to an erroneous estimation of V_o, the error which would result would be to fix incorrectly the neutral points, where there is no exchange of current between the rails and the earth, however, the parts of the zones where there is a large exchange will generally be well defined.

APPENDIX II

ELECTRICAL MEASUREMENTS

A. 2. 1. — INTRODUCTION

236 A. 2. 1. 1. — The making of electrical measurements may have as its object the collection of the necessary facts for the consideration of the different problems on the protection of cables, or other metallic underground pipes, against electrolytic corrosion due to stray current arising from direct current traction systems.

237 Amongst these various problems, very varied in complexity, may be cited, for example :

— Study of the nature of corrosion, and subsequently, the origin of the stray currents having caused it.

— Determination of the magnitude of stray currents discharged or collected in a short or a long length of electric railway track, or underground cable.

— Study of the general situation on a traction system from the point of view of the stray currents produced by it.

— Study of the general situation concerning the systems of underground cables or pipes within the field of the stray current.

— Determination of the requirements of a system of electric protection.

238 On the other hand, electrical measurements may simply be intended to ensure that certain conditions of co-existence of a traction system and a cable system are satisfied, and particularly that certain parts of the installations remain in a good condition.

239 A. 2. 1. 2. — The electrical characteristics to be considered first of all, are on one hand the magnitudes and densities of current, and on the other hand the differences in potential. As will be pointed out, when describing them, the direct measurements of the magnitudes and densities of current are often difficult or delicate. Thus it is often preferred to use indirect determinations, calculated from various measurements of the differences of potential, carried out with the necessary precautions.

240 The measurements of differences of potential are also those to which recourse is most often made, either for the control of a general situation, or for preliminary tests, especially if no special provision has been made previously for the connection of ammeters in the circuits.

241 The testing of the good condition of the rail joints is by the measurement of or comparison of resistances.

242 A. 2. 1. 3. — Most frequently, the interpretation of the results of measurements rests on the comparison of values of two or more different magnitudes (currents, densities of current, differences of potential) which depend, according to more or less complex laws, on the distribution of the currents throughout the tracks of the traction system. Now, this distribution varies, continuously as a function, of the volume of traffic and of the movements of the vehicles. Hence, it follows that special precautions should be taken to obtain data which can be correlated. The comparison of instantaneous values is not possible unless they have been obtained by means of simultaneous measurements. It is often necessary to work out average values from measurements taken over sufficiently long periods. These considerations play a part in the choice of the best methods and of the most useful equipment.

A. 2. 2. — APPARATUS FOR GENERAL USE

243 With the exception of certain methods depending on the use of special apparatus or equipment which will be described when their employment is necessary, the greater part of the measurements are taken by using instruments or accessories having common characteristics which will be indicated hereunder :

A. 2. 2. 1. — *Ammeters*

244 Ammeters are generally used for the measurement of current flowing along a metallic pipe or cable system, a rail, or a metallic connection, or the exchange of current (between rail and earth).

245 It is essential that the resistance of an ammeter, with its shunt, includin the resistance of the connections between the shunt and the conductor through which the current to be measured will flow, should be very low in order that the insertion of the apparatus should not tend to change the value of the said current. As a general rule, the resistance should not exceed 0.01 ohm.

246 Ammeters should be for measuring direct current only, they should be suitably sensitive, should give a rapid indication and preferably have a centre zero unless it is certain that the current to be measured is unidirectional.

A. 2. 2. 2 — *Voltmeters and Galvanometers*

247 Voltmeters are generally used for the measurement of differences of potential :

a) between two points, relatively distant (from a few metres up to several kilometres) on a single conductor, or on conductors of a single system, connected metallically to each other ;

b) between conductors (or between a conductor and a metal electrode) buried in, or in good contact with, the earth but not connected together metallically ;

c) between a non-polarisable electrode and a conductor, buried in or in contact with the earth ;

d) between two points very close together (for example, a few decimetres) on a single conductor, in order to determinate the current flowing in it ;

e) between two points on a system which are to be made equipotential (using a centre zero instrument).

248 These instruments should be for measuring direct current only, and should give a rapid indication ; it is generally useful for them to have a centre zero. Their resistance and their sensitivity should be chosen having regard to their conditions of use. Particularly, assuming the measurement of similar voltages, the resistance necessary for taking measurements (*b*) is much higher than that which would

suffice for taking measurements (*a*) and, for example, should be in the region of 10,000 ohms per volt at the maximum voltage measured. In the case of measurements (*c*) the resistance of the apparatus should be even higher; an electronic type of instrument is generally used.

249 In the case of measurements (*d*) and (*e*) where it may be desirable to measure fractions of a millivolt, and even of a microvolt, the resistance of the instrument (in ohms per volt at the maximum voltage measured) may be much lower. The voltmeter may often be replaced by a galvanometer, provided that this instrument is sufficiently dead-beat.

250 As an illustration, descriptions of various different apparatus used, more especially for the taking of measurements (*d*) and (*e*) are given below.

251 a) *Unipivot Voltmeter.* — The instrument has three scales each with a centre zero (from — 1.25 to + 1.25 mV; from — 25 to + 25 mV; and from — 250 to + 250 mV). It has a resistance of 8 ohms per millivolt. This instrument, using suitable shunts, may also be used as an ammeter.

252 b) *Millivoltmeter using a mirror galvanometer.* — The millivoltmeter used in the " Tester SA 9069 " of the British Telephone Administration is intended to measure the difference of potential between two points on a cable sheath, separated by about a metre.

253 The apparatus is a mirror galvanometer having a single loop of 10 ohms, and which has a sensitivity such that a deflection of 1 millimetre on a graduated scale, placed 17 centimetres from the mirror corresponds to 10 microvolts. This galvanometer may be connected to the cable sheath directly, or by means of shunts so that the sensitivity of the instrument may be one half or one fifth of full sensitivity. The maximum differences of potential which may be measured are, according to the sensitivity, + 500 μ V, + 1 000 μ V, or + 2 500 μ V. The scale is marked with three ranges corresponding to these sensitivities.

254 c) *Loop Galvanometer.* — This galvanometer consists of a loop of fine aluminium tape (of about 6 ohms resistance), suspended between the poles of two permanent magnets. The loop is extremely light, so that its deflection is aperiodic, it is enclosed within a glass globe in order that it may not be influenced by draughts. Its movements are observed by a micrometer microscope.

255 It is also possible to project on to a photographic film placed in a dark chamber the optical image of a small part of the loop lighted by an incandescent filament lamp, a single edge of the tape being focussed with precision on the film through the optical system: when the film is unrolled at a suitable speed a record is obtained.

256 The loop may be set up in two ways; according to the arrangement the apparatus will record several fractions of a microvolt or several microvolts. Its sensitivity may be decreased by adding a series resistance. Calibration is carried out by the application of a known voltage taken from a potentiometer.

257 In spite of its great sensitivity, the apparatus is but little influenced by mechanical vibrations, and may be used out of doors.

258 d) *Valve Voltmeter.* — The valve voltmeter, a schematic diagram of which is given in Fig. 1, is essentially composed of two high slope thermionic valves, of low grid current, connected in bridge and fed by dry batteries, with an indicating instrument connected between the two anode circuits.

259 The difference of potential to be measured is applied to a resistance of several megohms, connected to the grid of the first valve. The second valve connected symmetrically is used to balance the bridge and to compensate for unavoidable variations in supply voltage, as well as possible over-voltages.

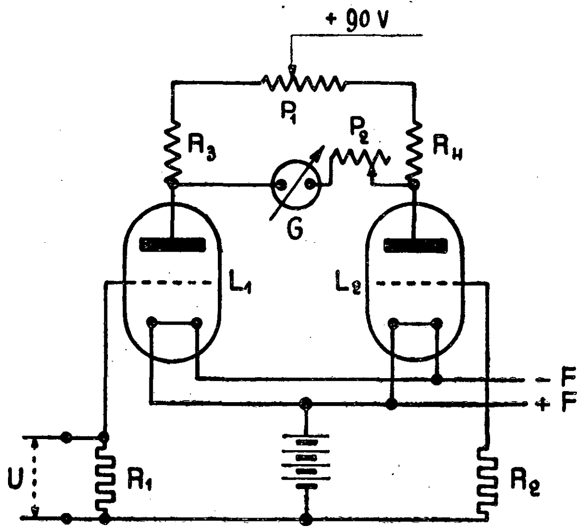

Figure 1

VALVE VOLTMETER

P_1 : Zero balance

P_2 : Scale adjustment

U : Difference of potential to be measured

260 The apparatus works as follows : when the voltage to be measured is applied to the resistance R1, the grid of the first valve is brought to a greater negative potential, which causes the anode current flowing in the resistance R3 to decrease. The anode of valve 1, which was initially at the same potential as that of valve 2 is made more positive, and the difference of potential between the two anodes gives rise to a current proportional to the voltage to be measured, and which is measured by the indicating instrument G.

261 The resistances R3 and R4, acting as anode impedances are arranged so that the valves work on the linear part of their characteristic. It thus follows that the deflections of the indicating instrument are proportional to the differences of potential applied to the resistance R1.

262 The apparatus is balanced to zero before it is used, and a source of direct voltage incorporated in the voltmeter serves as a standard and provides for the instrument to be calibrated at the maximum reading of the scale.

263 These two adjustments can be readily checked during use by the operation of a switch.

264 The calibration is carried out on the 1.5 V scale and no correction is necessary for the other scales which are automatically brought into line.

265 To allow for changes of polarity of the voltage to be measured, a reversing switch provides for the instantaneous reversal of the reading, this is necessary to keep the chassis of the voltmeter (positive terminal) at earth potential.

266 For certain measurements it is possible to change the zero, so as to have a central zero, while retaining the same scale readings.

267 The input resistance is 1 megohm per volt for the scales 0-1.5 V ; 0-5 V ; 0-15 V ; 0-50 V.

268 The resistances comprising the voltage dividers to give different sentitivities are chosen to be as stable as possible.

269 The framework enclosing the batteries is carefully insulated and comprises a copper covering formed in one piece, so as to avoid, in wet weather, any leakage of current from the batteries to the case itself and thence to the earth, which would cause variations in the measurements.

A. 2. 2. 3. — *Recording Apparatus*

270 The use of recording apparatus of the most common types is not possible except in a fairly limited number of cases. This type of apparatus is generally less sensitive than the indicating type, and the resistance is often too small : these disadvantages may be remedied by the use of direct current amplifiers (electronic, bolometric...).

271 The comparison of the instantaneous values given by recording apparatus is only permissible if the recordings are made on one and the same paper, or if the rates of movement of the recording papers are synchronised.

272 As typical examples, details of various special recording instruments are given below :

273 *a*) *Recording instrument which has been used by the British Telephone Administration* — The apparatus is composed of two loop-galvanometers placed side by side, and the movements of the loops are recorded on one photographic film under the conditions previously indicated. The film is driven by an electric motor, at a speed of between 3 cms and 10 cms per minute. This motor, as well as the projection lamps of the galvanometers, are fed by portable batteries, and the whole of the mechanism is easily transportable.

274 In order to equalise the loops, a resistance is provided in series with them, so that the same deflection is obtained when the same voltage is applied to them.

275 With these arrangements, it is possible to determine with precision the differences between the instantaneous values of the recorded voltages in two different places, even if they are varying rapidly.

276 *b*) *Schlumberger recording instrument* — The difference of potential to be measured is applied to two terminals O and L ; it is connected in series with a moving coil galvanometer G having a centre zero, in parallel with a difference of potential obtained from the two sliding contacts U and D on a double decade resistance placed in the circuit of a battery (fig. 2). By means of auxiliary resistances in series and parallel, the apparatus has four sensitivities and allows measurements from 0.05 mV to 500 mV.

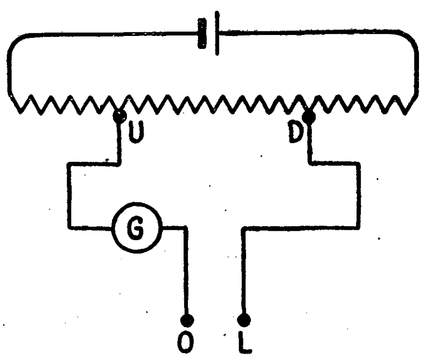

Figure 2

277 The potentiometer is arranged in the recording instrument as follows :

278 A hand operated dial moves the units knob in a continuous movement, by a mechanism similar to that of a revolution counter, so that each time the units knob makes a turn, the tens knob is given one tenth of a turn.

279 The dial has on its underside a grooved Archimedian screw. A fixed catch on a horizontal guide slides in this groove. When the dial is turned, the guide advances or retires proportionally to the number of turns and therefore to the indications of the knob of the potentiometer, i.e. to the differences of potential measured. These displacements are recorded by a pencil fixed at the end of the guide, on a band of paper moving in a uniform manner perpendicular to the movement of the guide, under the action of a spring motor.

280 The synchronisation of the recordings made simultaneously on several instruments is ensured by the simultaneous periodic inscription of periods of time.

281 The sensitivity of this method is due principally to the fact that :

1. The operator may change instantaneously to the most favourable scale,
2. The power necessary for the working of the recording instrument is supplied by the operator and not by the current in the galvanometer.

282 This method of recording has shown itself perfectly adaptable to the measurements of stray currents.

A. 2. 2. 4. — *Integrating apparatus.*

283 It is possible to obtain an average value relative to a certain duration, by determining, for example by means of a planimeter, the average ordinate of the curve resulting from either sufficiently regular readings, or from the record furnished by a suitable recording apparatus. Integrating apparatus of the common type (ampere-hour meters, volt-hour meters, watt-hour meters) may be used within the limits which their characteristics allow, for carrying out the measurements in question, subject of course, to it being certain that the direction of the magnitude being integrated does not change during the period of each operation.

A. 2. 2. 5. — *Points of connection*

A. 2. 2. 5. 1. — *Metallic connections*

284 The connections by which a voltmeter is connected should be stable and should have as low a resistance as possible. They should be of the same metal as that to which connection is made in order that, should there be any moisture present, the formation of a galvanic couple is avoided. In the case of cast-iron or steel rails or ducts, use may be made with advantage of spiked, knife-blade, or saw-toothed contacts either tightly fixed together or magnetised ; the rail or the duct is first scraped clean. In the case of cable-sheaths, preferably soldered or tightly fixed connections are used.

A. 2. 2. 5. 2. — *Earth connections.*

285 The contact of the soil with a simple metallic electrode, even chemically inert, gives rise to an extremely uncertain polarisation electromotive force, generally varying as a function of the current passing through the electrode and also having very variable values according to the part of the ground where the electrode is placed.

286 However, for rough and ready measurements, an earth spike made of metal not easily polarised (for example, a copper spike) may be used. In the case of cable-sheaths of lead, or lead-alloy, acceptable results are obtained by using an electrode of the same material as the sheath, and placed in contact with the damp

soil ; if the measurements are made in a duct or chamber, it is possible to use an electrode consisting of a lead sleeve, containing a sponge saturated with water taken from the duct or the chamber and kept in contact with the floor of the latter. Where necessary, it is possible to use as an earth connection, a buried metallic structure provided it is not connected to any other metallic pipe system.

287 In every case, the contact area between the earth electrode and the soil should not be too small in order to avoid excessive polarisation.

288 For precise measurements a non-polarisable electrode should be used.

A. 2. 2. 5. 3. — *Non-polarisable electrodes*

289 The use of non-polarisable electrodes was at first confined to research work ; for some time now simple types of electrodes have been available for making measurements on the surface or for drawing through a duct with a view to making measurements at points otherwise not directly accessible.

290 Non-polarisable electrodes have an electromotive force depending on their composition, but which remains sufficiently stable provided that precautions are taken when they are used. This electromotive force is added to the difference in potential being measured ; therefore it must be previously known.

291 The contact resistance of non-polarisable electrodes with the soil or with the wall of a chamber or duct is often very high, and moreover indefinite. Also, the electromotive force of the electrode is not independent of the value of the current flowing through it. These two causes of uncertainty may be eliminated by measuring the differences of potential using a potentiometer, or by using a voltmeter of sufficiently high resistance.

292 *a*) *Calomel Electrodes* — The Calomel Electrode is a standard of reference for determining the magnitude which in electrochemistry is designated by the term « potential ».

293 1) The laboratory apparatus is constructed in a tubular form. At the base of the tube there is placed a bath of pure mercury covered by a layer of pure calomel (mercurous chloride). The electrolyte placed above is a pre-determined solution (usually a normal solution) of potassium chloride saturated with calomel. The contact with the mercury is made through a platinum wire sealed through the glass. The other contact is made by a liquid connection made up of a saturated solution of potassium chloride contained in the glass tube.

294 The agreed " absolute potential " of the normal calomel electrode is $+ 0.24$ volt at 25^{o} C.

295 A calomel electrode has been used by the British Telephone Administration for measurements in ducts, under the following conditions : two electrodes protected against shock and variations of temperature by rubber and cotton were mounted in a box. Contact with the water of the duct was established, by lenthening the glass tube used normally for making the liquid connection, by means of a rubber tube, itself filled with a saturated solution of potassium chloride, and terminated by a probing attachment of ebonite, filled with a thick jelly of agar-agar and of water taken from the duct in question, in order to reduce to a minimum the magnitude of the liquid junction potential. The probing attachment was connected to a number of probes pushed into the duct-way containing the cable in question, or into a neighbouring duct-way.

296 2) In the United States of America, a calomel electrode has been produced which may be drawn into a duct. It is placed in a support formed from a strip of lead which serves as a mechanical protection for the electrode.

297 *b*) *Lead chloride electrodes* — This type of electrode, made for drawing into ducts, consists of an ebonite shell, perforated, and filled with an agar-agar jelly containing a saturated mixture of lead and potassium chlorides, with an addition of glycerine to prevent the too rapid dehydration of the agar-agar. Lead rings placed on the exterior of the shell provide mechanical protection. (figure 3).

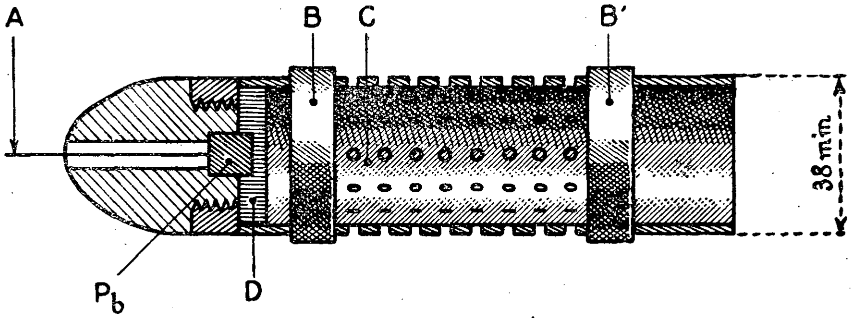

Figure 3

LEAD CHLORIDE NON-POLARISABLE ELECTRODE

A : Connecting wire to lead electrode
B, B′ : Lead rings surrounding the electrode
C : Perforated ebonite shell
D : Paste : $PbCl_2 + KCl$

c) *Copper sulphate electrodes.*

298 1) The electrode is composed of a tube of metallic copper fixed in a porous pot containing a saturated solution of copper sulphate, with an excess of crystals, made with distilled water.

299 The electrical contact of this electrode with the soil is through the moisture filtering through the porous wall. Normally it has a high resistance,

300 The agreed " absolute potential " of this electrode is + 0.32 volt at 25° C.

301 The electrode may also be made up as follows. A sponge soaked in copper sulphate solution is placed in a moulded box ; a copper stem is fixed on the base of the box and penetrates the sponge. A certain quantity of copper sulphate crystals is placed between the sponge and the bottom of the box. During transport the box is covered with a lid thus enclosing the sponge.

302 2) Figure 4 shows a model made by the British Telephone Administration which can be drawn into a duct.

303 3) The model described below, employed in special cases, was designed to have a relatively low resistance (some tens of ohms). The electrode is essentially composed of a wooden tube as porous as possible (about 50 to 60 cms in length and 4 to 5 cms internal diameter). On this tube are fixed, first a winding of textile, and then a winding of ten copper wires in parallel (altogether 55 metres of copper wire of 45/100 mms. in diameter, under two layers of cotton). The whole is covered by a plaiting of whipcord. The wooden tube is closed at one end by a cork through

which the cable passes which is soldered to the copper wire and intended to provide the connection of the electrode to the measuring apparatus. Precautions are taken to avoid contact between the tin of the solder and the electrolyte in passing the cable through the cork.

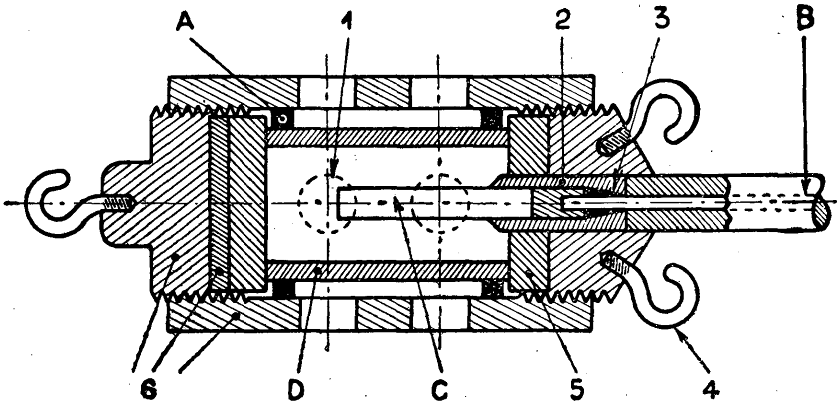

Figure 4

COPPER SULPHATE NON-POLARISABLE ELECTRODE
(FOR DRAWING INTO A DUCT)

A : Ebonite spacer
B : Flexible connection
C : Copper Rod
D : Porous Pot

1 : Filled with saturated copper sulphate and china clay paste
2 : Marine glue
3 : Solder
4 : Copper
5 : Rubber
6 : Ebonite.

304 When the electrode has been set up, it is soaked in two successive solutions of copper sulphate.

305 The interior of the wooden tube is filled with a mixture of equal volumes of finely powdered copper sulphate and of sawdust.

306 The electrode is normally kept in a solution of copper sulphate.

307 When using these electrodes in very wet soil or other wet situations the copper sulphate solution has been found to spread in a short time to the middle part of the electrode. Thus the solution concentration may change without it being brought to notice.

308 This inconvenience can be avoided however by mounting this electrode in a perspex base, the bottom of which is a porous pot which serves as an electrolytic diaphragm. The perspex allows one to see very easily the state of the copper sulphate solution and verify the presence of the crystals.

A. 2. 3. — MEASUREMENT OF DIFFERENCES OF POTENTIAL

A. 2. 3. 1. — *Measurements between different points, either on the same metal structure or duct, or between different metal structures or ducts.*

309 For these measurements a voltmeter connected to two contact points is used.

310 The precautions to be taken in choosing the instrument, and in making contact have been given above. When the two points, between which the difference of potential is to be measured, are distant from one another, pilot wires are used : unless the resistance of the voltmeter is large as compared with the resistance of these wires, it is necessary to correct the measurements to make allowance for their resistance.

A. 2. 3. 2. — *Measurements between one point of a metallic structure or duct and earth.*

311 It is generally not possible to give absolute values to the results of measurements of differences of potential between a metal structure or duct system and earth, since the results depend largely on the nature of this earth connection (polarisation), on its position (potential gradient due to stray currents possibly exchanged between a nearby structure and the earth) and the points of contact (galvanic couples).

312 However, when the value of the measured difference of potential greatly exceeds the limits of uncertainty due to these causes, the measurement of the difference of potential between a metallic structure or duct system and a nearby point in the earth indicates the direction of the exchange of current between the metal and the earth and also gives an idea of the magnitude of this exchange.

313 On the other hand, if causes of uncertainty in the measurements of the differences of potential do not vary, the values of the variations of this magnitude, which may be deduced from the measurements, retain their full value.

314 Furthermore, useful information may be drawn from the comparison of either the results of such measurements carried out at different times, at the same places and under the same conditions, or from the results of such measurements and those of other measurements carried out simultaneously.

A. 2. 4. — DETERMINATION OF THE MAGNITUDE OF CURRENT, EXCHANGES OF CURRENT AND DENSITIES OF CURRENT

A. 2. 4. 1. — *Measurements of the current flowing in a metal cable sheath.*

315 These measurements can only be carried out in places where the cable is accessible (chambers in the case of cables drawn into ducts, or excavations in the case of buried cables).

316 Except in the case of direct measurements, the cable must be accessible at least over a length of the order of several decimetres or a metre.

317 In the case of armoured cables, if it is desired to measure the total current flowing in the sheath and the armouring, these should be bonded to each other on both sides of the points of attachment of the measuring apparatus.

318 A. 2. 4. 1. 1. — *Direct measurements.* — The measurement is made by interrupting the continuity of the cable sheath and by inserting an ammeter, satisfying the requirements specified earlier; the resistance of the ammeter with its shunt should never exceed 0.01 ohm.

319 A. 2. 4. 1. 2. — *Measurements by compensation.* — The stray current circulating in the cable sheath may be measured by compensating the stray current, by means of another current, derived from an auxiliary battery as shown in figure 5.

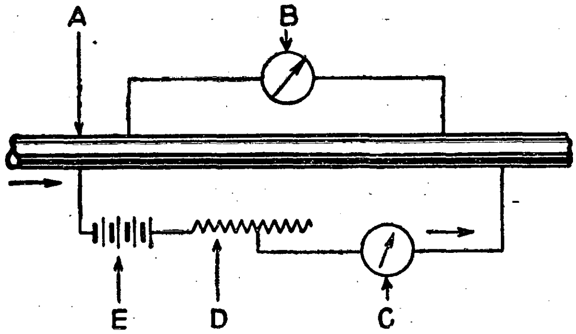

Figure 5

COMPENSATION METHOD FOR THE MEASUREMENT OF CURRENT FLOWING IN A CABLE SHEATH

A : Cable B : Centre zero galvanometer
C : Ammeter D : Rheostat
E : Auxiliary battery

320 The current flowing from the auxiliary battery passes through an ammeter, a rheostat, a reversing switch and a short length of the cable under test. A centre zero instrument (voltmeter or galvanometer) is connected across the length of the cable sheath preferably by soldered connections placed at some centimetres from the compensation circuit connections and between them; the rheostat is adjusted until the pointer of the voltmeter indicates zero, and then the reading is taken, on the ammeter, of the stray current flowing in the cable sheath.

321 The use of this method is only possible when there are no frequent reversals or very rapid variations of the current in the cable sheath under test.

322 A. 2. 4. 1. 3. — *Voltmeter method.* —. It is possible to determine the current flowing in the cable sheath by measuring the voltage drop in a short section, the resistance of which is known.

323 This voltage drop may be measured either by means of a sensitive voltmeter, whose resistance should be much greater than that of the section of cable sheath under consideration, or by means of a potentiometer using an opposition method.

324 The use of the opposition method is only possible when there are no frequent reversals or very rapid variations of the current in the cable sheath under test.

325 The electrical resistance of the short section of cable sheath may be:

a) either calculated (if the sheath is uniform), according to the cross-sectional area and the resistivity of the metal;

b) or measured by means of an appropriate ohmmeter, using an interrupted or alternating current,

c) or measured, by passing a known current obtained from an auxiliary battery, and measuring simultaneously the fall of potential on the section of cable sheath. It is important, that either the current used should be much greater than the stray currents flowing in the sheath, or that the measurements should be taken when no stray current is flowing in the sheath. If the stray current is sufficiently constant during the measurement, a smaller auxiliary current may be used and the effect of the stray current can be eliminated by taking two successive measurements with the auxiliary current reversed.

326 Methods (*b*) and (*c*) are sufficiently accurate even if the cable under test is bonded to other cables of the same underground system or is connected to earth nearby but outside the short section in question, provided that the bond or the earth connection exists on one side only of the said short section.

A. 2. 4. 2. — *Determination of exchanges of current between a cable and earth or between a track and earth.*

327 The determination of the total value of the current exchanged between a certain section of cable or track and the earth, may be deduced from the result of measurements of current in the cable or the track, made at the ends of the said section. These measurements should be made at one and the same time, so that it is possible to determine the difference between simultaneous measurements. Direct measurements may be taken in the case of cables, either by the interrupted sheath or the " test-sleeve " method which require a special treatment of the section in question, or by the method of the double bridge with constant arms, or with variable arms, which makes use of special apparatus. This last method may also be used in the case of traction routes.

328 The preceding methods require access to the cable. Owing to their lack of sensitivity they are only applicable in practice in cases of long sections, except for the interrupted sheath or the " test-sleeve " methods. They give an overall result and do not provide the exact value of the exchange of current, nor even the direction in the different points of the section.

329 On the other hand in the case of cables buried direct in the ground, this latter information may be obtained by the application of the Schlumberger and Gibrat method which only requires measurements to be made on the surface of the earth in the vicinity of the cable, and which may be quite accurate, at least as far as variation of current is concerned. In the case of cables drawn into ducts the method will only give the value and direction of the current exchanged over the whole length of the duct.

330 Measurements of exchanges of current with the earth are generally taken over a more or less extended period (fifteen minutes at least, and even several hours, or a day), with the object of obtaining average values.

331 A. 2. 4. 2. 1. — *Method of simultaneous measurements.* — Measurements of current should be taken by means of identical apparatus well balanced with respect to each other, and sufficiently dead-beat ; more often than not these measurements are made by a voltmeter method.

332 *a*) Measurements may be made by two operators, who, for example, take readings every ten or fifteen seconds : this method should be carried out by experienced operators, and only gives satisfactory results when the graphs of the results obtained differ considerably.

333 *b*) It is also possible to use two synchronised recording instruments having suitable sensitivity.

334 The recording instrument used by the British Telephone Administration, previously described, was specially designed for such measurements : a few milliamperes of current flowing in the sheath of a large cable is sufficient to give a legible reading on the film when the galvanometer is connected across about a metre of cable. Synchronisation of the records is effected by recording on a single film.

335 A. 2. 4. 2. 2. — *Interrupted sheath method.* — This method may be used in the case of non-armoured cables. At each end of the section under consideration

a break is made in the cable sheath. The cable sheaths on either side of the section thus made, are connected to each other by an insulated conductor the resistance of which should be approximately equal to that of the section of cable sheath between the breaks. Current measuring apparatus is connected across one of the breaks ; this indicates the value and the direction of the current exchanged between the section of sheath and earth (see figure 6).

Figure 6

MEASUREMENT OF THE EXCHANGE OF CURRENT BETWEEN A CABLE AND EARTH BY BREAKING THE CONTINUITY OF THE CABLE SHEATH

336 A. 2. 4. 2. 3. — " *Test-sleeve* " *method.* — *a*) A metal sleeve, or " test sleeve " is placed all round the sheath of the cable being measured, and is separated from this sheath by an insulating layer. The excavation necessary for putting this arrangement into place is reinstated so as to reconstruct the previous conditions as far as possible. Insulated conductors A and B soldered respectively to the sheath and to the tube, emerge from the soil, and current measuring apparatus is connected between these conductors (see Figure 7).

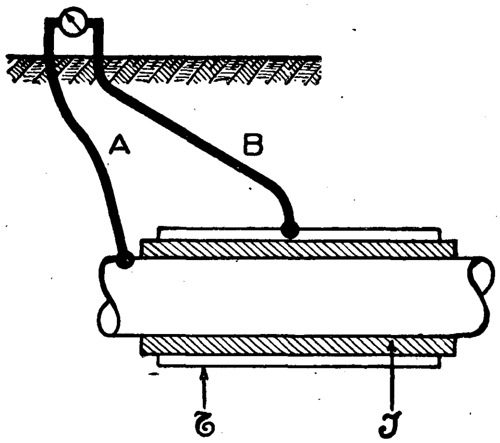

Figure 7

" TEST-SLEEVE " METHOD OF MEASURING THE EXCHANGE OF CURRENT BETWEEN A CABLE AND EARTH

𝒥 : Insulator 𝒞 : Test-sleeve

337 The external diameter of the " test-sleeve " should be as nearly as possible the same as that of the cable under test ; its surface should be of the same metal, and should present, as far as possible, the same conditions of contact with the soil as the cable, so that the conditions of exchange of current with the earth are the same as those of the cable. If these conditions are complied with this method will give information on the magnitude of the current exchanged between the cable and the earth.

338 *b*) In the case of armoured cables, use may be made of the armouring to constitute the " test-sleeve ". The armouring wires are cut at the ends of the length, along which it is desired to measure the exchange of current with the earth ; at one end they are connected together, for example by means of a soldered wire, and connected to the current measuring apparatus. On either side of the said section the armouring wires are connected together, and also connected to the lead cable sheath.

339 A. 2. 4. 2. 4. — *Method using a double bridge with fixed arms* (figure 8). — Let A_1 B_1 and A_2 B_2 be the ends of two sections of cable, chosen so that they have the same electrical resistance R. These points are connected to a double bridge of four resistances r_1 and r'_1, r_2 and r'_2, each equal to the other, in the diagonal of which is connected a galvanometer of resistance r_g.

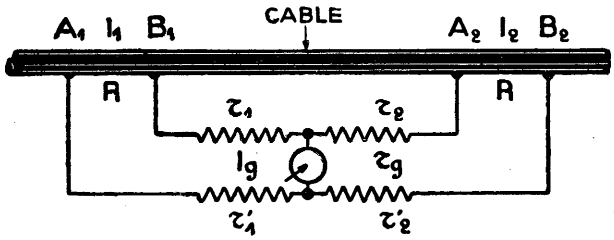

Figure 8

METHOD USING A DOUBLE BRIDGE WITH FIXED ARMS
FOR MEASURING THE EXCHANGE
OF CURRENT BETWEEN A CABLE AND EARTH

340 The common value *r* of these four resistances should be such that the double bridge does not divert a large current from the cable.

341 If I_1 is the current flowing in the section of cable A_1 B_1,

I_2 is the current flowing in the section of cable A_2 B_2,

and I_g is the current flowing through the galvanometer, it follows that :

$$I_1 - I_2 = \frac{-2\,(r + r_g)}{R}\,I_g$$

342 If R, r and r_g are known, the loss of current between the two sections is obtained from the galvanometer reading.

343 If the resistance r_g of the galvanometer is large with respect to the resistance r of each of the four arms of the double bridge we have simply :

$$I_1 - I_2 = - \frac{-2v_g}{R}$$

v_g being the voltage at the terminals of the galvanometer, which may then be a millivoltmeter, having for preference a centre zero.

344 A. 2. 4. 2. 5. — *Method using a double bridge with variable arms* (figure 9). — This method provides for the direct determination of the ratio of the currents flowing in two short sections of cable, or the ratio of the currents flowing in two short sections of track.

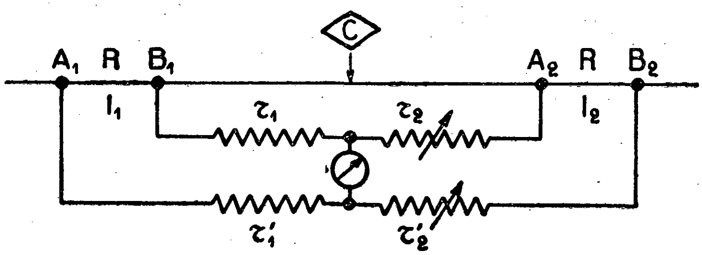

Figure 9

METHOD USING A DOUBLE BRIDGE WITH VARIABLE ARMS FOR MEASURING THE EXHANGE OF CURRENT BETWEEN A CABLE OR RAIL AND EARTH

C : Cable or rail

345 Let A_1 and B_1, A_2 and B_2 be the ends of two elements of cable of the same resistance R, the equality of which may be verified by measuring these resistances by one of the numerous suitable methods.

346 These points are connected, as shown in the figure, to the ends of a double bridge of four resistances r_1 and r'_1, and r_2 and r'_2 chosen so that the current diverted by the bridge is negligible with respect to that flowing in the cable or the track. A galvanometer is connected in the diagonal.

347 The resistances r_1 and r'_1 are fixed and equal to each other. The resistances r_2 and r'_2 are variable but are so arranged that their variations are simultaneous and their values are always equal to each other.

348 This being so, the principle of measurement is to adjust the current flowing through the galvanometer to zero by suitably adjusting the ratio

$$\frac{r_1}{r_2} = \frac{r'_1}{r'_2}$$

349 In these circumstances,
if I_1 is the current flowing in the element A_1 B_1 and I_2 is the current flowing in the element A_2 B_2,

$$\frac{I_1}{I_2} = \frac{r_1}{r_2}$$

350 If the values of the resistances of the arms of the bridge are known and the potential drop in one of them is measured, it is possible from the results of the measurements on the double bridge, to deduce the exact value of the loss of current between the sections A_1 B_1 and A_2 B_2.

351 As described above the method is only applicable if I_1 and I_2 are in same direction. In the case of measurements made on an electric traction system, this excludes the possibility of taking measurements when there are vehicles between points A_1 and B_2.

352 On the other hand, a section of route has at least two rails and sometimes four. In order that the measurements should have any meaning, it is necessary, in the sections under consideration, that the distribution of the current should be uniform between the rails. To obtain this result, transverse welded connections, of sufficiently low resistance are made on each side of the sections A_1 B_1 and A_2 B_2. Figure 10 shows the dispositions of these connections, and indicates an order of magnitude of the lengths of section and of the distance between sections regarded as suitable. In these conditions, tests have shown that the distribution of the current between the rails was sufficiently uniform so long as the moving vehicles were some dozens of metres distant from the transverse connections.

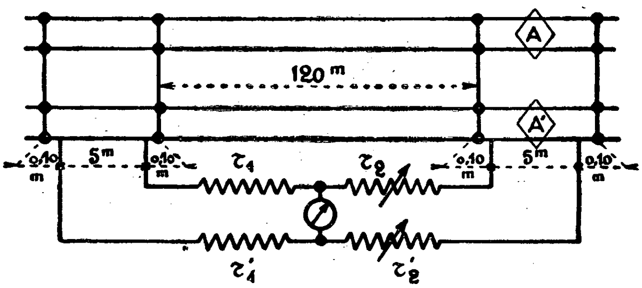

Figure 10

METHOD USING A DOUBLE BRIDGE WITH VARIABLE ARMS FOR MEASURING THE EXCHANGE OF CURRENT BETWEEN RAILS AND EARTH, IN THE CASE WHERE THERE ARE SEVERAL RAILS

A = Rails

353 This easily applied method permits the determination of the dispersion of current along a short section of rail and also the characteristics of dispersion in a traction network and permits the periodic control of such sections of rail or of the complete network.

A. 2. 4. 2. 6. — *Method of Schlumberger and Gibrat.*

354 a) *Object and principle of measurements.* — The object of the measurements is to determine the value of exchanges of current between a buried pipe system and the surrounding earth. The principle of this determination is based on the differences in potential at the surface of the earth and the resistivity of the ground and from them the value of the exchanges of current is deduced.

355 Between two points on the surface of the earth, the difference of potential may be resolved into three elements :

α) A difference of potential arising from the exchange of current between the pipe system and the earth;

β) a difference of potential arising from currents having other origins (other pipe systems, tramway tracks, earth currents, etc.);

γ) a difference of potential arising from the electrochemical effects due to variations in the nature of the ground.

356 If the sources of disturbance are sufficiently distant and if in the locality of the measurements the soil is homogeneous, the second field considered will be practically uniform over a short distance, and the corresponding variations of potential, in any one direction will be linear.

357 b) *Description and use of differential apparatus* (figure 11). — The differential apparatus is intended to eliminate the effects of uniform fields. It is composed of three equidistant copper sulphate non-polarisable electrodes M, O, N, placed in a straight line.

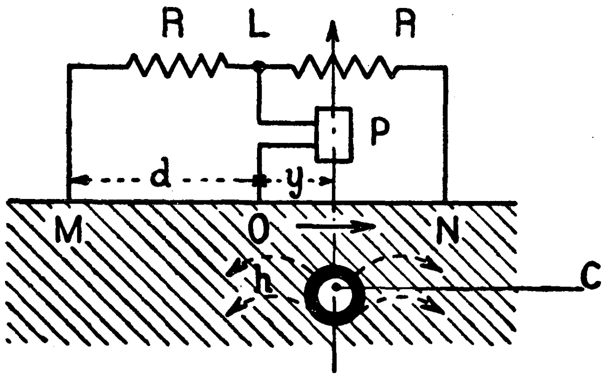

Figure 11

DIAGRAM OF DIFFERENTIAL APPARATUS FOR MEASURING THE EXHANGE OF CURRENT WITH THE SOIL

P : Galvanometer and potentiometer R : Resistances
C : Cable or Pipe

The full arrow indicates the general stray current; the broken arrows indicate the exchange current.

358 The centre electrode O is connected to a Schlumberger potentiometer recording instrument (see par. A. 2. 2. 3. b.), the second terminal of which is connected to electrodes M and N, through two resistances. These resistances are very high in order to obtain a very low current between M and N which is negligible in regard to stray current in the region MON; furthermore, a special arrangement provides for the variation of one of the resistances R so as to compensate the difference which may exist between the contact resistances at M and N. The potential of the second terminal of the potentiometer is thus made equal to the average of the potentials of the soil at M and N; therefore if the general stray current in the soil between M and N is uniform, and if the soil is sufficiently homogenous over this distance, the potential of the electrode in the centre will also be equal to the average potential of the outer electrodes; the reading on the measuring apparatus will be nil.

359 In practice, the distance between consecutive electrodes is either 0.5 m. or 1 m. and the uniformity of the field of general stray current can be assumed in the majority of cases. But, if in the neighbourhood of the centre electrode there exists a conductor exchanging current with the soil, the potential of this electrode will no longer be equal to the average potentials of the outer electrodes. It is possible therefore to observe, by means of a galvanometer, the effect of this current distinct from any other effect.

360 In most cases a sufficient approximation is obtained by calculating the exchanged current as if the exchange were uniform along an infinite length of pipe or cable.

361 When various discharging underground pipe or cable systems are in such close proximity to each other that it is impossible for the differential apparatus to be influenced by one to the exclusion of the others, it is possible, by moving the three electrodes across the underground systems, to draw a " transverse outline " of the measurements taken and to calculate the discharge of the different systems.

362 c) *Measurements of resistivity.* — The calculation of the linear density of the current exchanged requires a knowledge of the resistivity of the soil. This is determined, for example by the four-electrode method.

363 d) *Simultaneous recordings.* — In practice, it nearly always happens that the measurement of exchanges due to rapidly varying stray current arising from a nearby electric traction route, is involved; in which case measurements should be carried out successively in different places. Furthermore, it may be that the differences of potential between electrodes and various points of the soil are not negligible with respect to the values of the voltage generated only by the stray currents between the points L and O of the differential apparatus. Comparable measurements are obtained and moreover the constant voltages which are not due to stray currents can be eliminated, by recording simultaneously the voltage between the track and the earth and the differential measurement. In most cases, the variations of the two quantities are approximately proportional; the proportion between the variation in the differential measurement and the variation in the voltage between track and earth is characteristic for each measurement.

A. 2. 4. 3. — *Determination of the density of current in the earth.*

364 Certain methods (Haber, Mc Collum) based on the same idea, have been proposed to determine the density and the direction of current in the soil. In principle the conditions of exchange of current between the earth and a conductor buried directly in the earth are considered.

365 In the case of a cable in a duct, only the area in which the current passes from the duct into the earth can be determined : in practice, this area is often different from that where the current passes from the cable sheath to the body of the duct.

366 These methods necessitate excavation, in order to put the underground electrodes in place, which has the effect of changing the conditions it is desired to consider, and to affect seriously the results of the measurement.

A. 2. 5. — MEASUREMENT AND CHECK OF THE RESISTANCE OF RAIL JOINTS

367 It is agreed that the term rail-joint resistance, shall be the resistance measured between two contact points placed on a line of rails, on either side of a joint, at a distance apart of some 0.5 m. or 1 m. a deduction being made for the resistance of the sections of rails included.

368 The methods indicated below determine the length of rail the resistance of which is equal to that of the joint.

369 On fairly extensive systems having a sufficient number of rail joints, a vehicle can be equipped for the rapid and frequent testing of the track by detecting joints which appear to have a high resistance. These can be checked and measured in due course.

A. 2. 5. 1. — *First method* (figure 12).

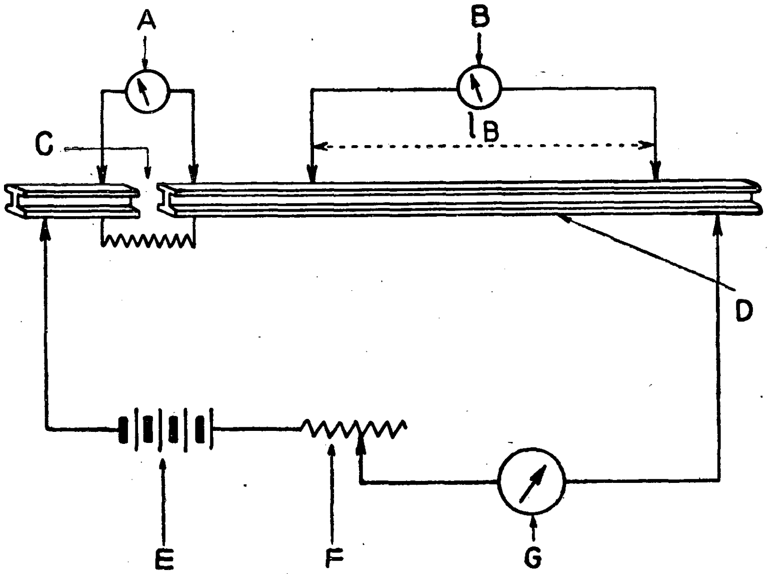

Figure 12

MEASUREMENT OF RAIL JOINTS BY THE COMPARISON METHOD

Note. — The connections shown in the lower part of the diagram are not made unless current is supplied from an auxiliary source.

A :	Voltmeter A	C :	Joint	E :	Auxiliary battery
B :	Voltmeter B	D :	Rail	F :	Rheostat
		G :	Ammeter		

370 *a*) A millivoltmeter A is connected across the joint to be measured. A second millivoltmeter B is connected across a length of rail l_B, not including a joint, of some metres in length; when a current is flowing in the rail, readings are taken on the two meters.

371 If V_A and V_B are respectively the measured potential differences, x the length of rail with resistance equal to that of the joint, increased by the sum of the lengths of the sections of rail enclosed, we have :

$$x = l_B \frac{V_A}{V_B}$$

372 It is desirable that the section l_B should be within a short distance of the joint under consideration, and of such length as accuracy in reading the millivoltmeter B allows.

373 This method may make use of either the traction current itself, or a current produced from an auxiliary source, of the same order as the traction current.

374 *b*) A variation of this method, using current from an auxiliary source, consists in using a simple galvanometer, connected across a fixed length of continuous rail, instead of millivoltmeter B and by fixing the current so that the millivoltmeter readings have a pre-determined value. The millivoltmeter A may then be appropriately graduated to show directly the length of rail equal to the joint, from the point of view of electrical resistance. This method is quite accurate.

375 *c*) Another variation of this method uses two galvanometers, of which the pointers cross each other above a special scale. The position of the point of crossing indicates directly the length of rail of resistance equivalent to that of the joint. The measurement is taken without any adjustment by making use of the traction current, or of a current supplied by an auxiliary source.

A. 2. 5. 2. — *Second method* (Wheatstone bridge) (Figure 13).

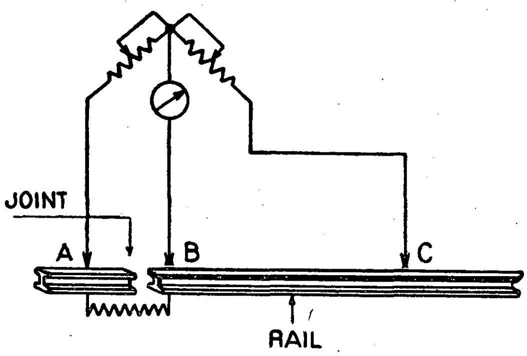

Figure 13

MEASUREMENT OF RAIL JOINTS BY THE WHEATSTONE BRIDGE METHOD

376 The figure indicates the principle of the method which may be applied in two ways :

a) The distance BC representing a known length of rail, the resistance of the other arms of the bridge are adjusted so that the galvanometer indicates zero; knowing the ratio of these resistances it is possible to determine the length of rail, which has a resistance equal to that of the joint.

b) The resistances of the arms of the bridge being equal and fixed, the contact C is moved along the rail until the galvanometer is again at zero. The length BC is the length of rail having a resistance equal to that of the joint increased by the sum of the lengths of the sections of rail enclosed in the part AB.

377 The two variations indicated may be applied while the system is in use the current necessary for measurement being already present in the rails.

378 However, if this current has rapid and frequent variations so as to make this method of measurement impracticable during the hours of traffic, the method may still be applied by passing a large and stable current, supplied by an auxiliary source along the rail from A to C, in place of the traction current.

A. 2. 5. 3. — *Third method.*

379 This method of which the conditions of use are the same as those of the Wheatstone bridge, consists in replacing the two arms and the galvanometer, by a differential galvanometer, the two windings of which have a common point, connected at B.

380 *a*) One winding being connected across BC, length fixed and known, the value of a resistance connected between the second winding and the point A is adjusted to bring the galvanometer to zero. A calibrated scale indicates the equivalent length of rail and the value of the resistance placed in series.

381 *b*) It is also possible to use two equal windings without adding a resistance and to obtain the zero on the galvanometer by moving the contact C along the rail.

A. 2. 6. — CHECK OF THE GENERAL CONDITIONS OF A TRACTION SYSTEM

382 It is desirable to determine the average value, over a long period (for example a day, or even a certain period of operation during a day) of :

a) the current flowing in the different return feeders,

b) the differences of potential between a reference point, chosen arbitrarily, and different points on the rail system, particularly the points of connection of the feeders, the ends of routes, or the points where they are broken . . .

383 Where in the vicinity of a rail network, there is a system of underground metallic cables or ducts which are good conductors, and of which the electrical continuity is ensured, it may be assumed that along the length of this cable or duct system, the variations of potential are generally much lower than are the differences of potential measured between a point on the rails and a nearby point of the cable or duct system. Thus one may assume as a fairly rough approximation, that the cable or duct system is equipotential, and also if the length of the system is sufficient, that its potential is little different from that of the earth at an infinitely distant point : this potential may then be adopted as reference potential.

384 On this hypothesis, it is possible to compare the results of the calculation of the differences of potential between the rails and the earth carried out as indicated in Appendix I, with these measurements. Experience shows, in practice, that if the joints of the track are in good condition and if the estimate of the relative values attributed to the coefficients of flow is good, the measured and calculated values agree satisfactorily : a disagreement is generally explained by the fact that the values attributed in the calculations to the coefficients of flow do not correspond to the real values in some sections of route (for example owing to the existence of a metallic connection between the rail and an underground duct or cable system the existence of which was unknown at the time of calculation).

385 When it is desired to obtain an average value over a long period of the current or the difference of potential and it is impossible to carry out measurements over a sufficiently long period of time, sometimes the following method may be adopted : the tests are carried out over a period of twenty minutes or half an hour during the peak traffic period. In order to relate the results observed during the tests to the whole of the period under consideration, it is necessary to measure, at the same time, the load of the electric traction route. Then the average of the voltages measured during the tests is multiplied by the ratio between the average load of the route considered over the whole of the period on the one hand, and the average load during the tests, on the other hand. These average loads are easily found by noting the different readings on watt-hour meters placed in the sub-stations or in the feeders.

386 Nevertheless, it is very important that the load values used in the calculations only concern the power supplied to the section of route under consideration. By the same argument, it is important to avoid the possible errors should one or more sub-stations not be running during part of the long period for which the average is sought.

A. 2. 7. — CONTROL OF THE GENERAL SITUATION OF A CABLE SYSTEM FROM THE POINT OF VIEW OF EXPOSURE TO ELECTROLYTIC CORROSION

387 The determination of the zones in which cables are most exposed to electrolytic corrosion may be made from the measurement of the current flowing in the cable sheaths, at different points on the route. These measurements may be supplemented and, if their execution is very difficult, even replaced by measurements of the differences of potential between the cable and the earth.

388 It is desirable to correlate these measurements with those of the load of the nearby traction systems. On the other hand, these measurements should be taken over a period of time to allow the calculation of an average value.

389 In certain cases it may be an advantage to install permanent apparatus for the measurement of voltage between a cable sheath and a nearby buried electrode in order to discover if the situation of the cable remains static or changes from the point of view of exposure to electrolytic corrosion.

390 When it is suspected that the stray currents due to one or more electric traction systems are affecting cables placed at a great distance from the tracks from which they originate, the determination of the electrical condition of theses cables from measurements made under normal operating conditions of the systems is made difficult by the fact that the stray currents change continually in intensity, in direction, and in polarity. Good results have been obtained by the use of the following method :

391 At night, when the tramway or electric railway services are not operating, or may be temporarily interrupted, currents of known value are fed from the electric traction system, between the contact line and the rail, at a certain number of points chosen in advance. At the same time, at suitable points, the currents appearing simultaneously in the cable sheaths are measured. These experiments may be supplemented by measurements (made at particular points) of the currents and voltages appearing when the traction system is running normally.

392 In the case of a tramway system, the " artificial " loads, mentioned above, are generally obtained by means of resistances connected between the contact line and the track for a period of half a minute to two minutes. In the case of an electric railway system, it has been found suitable to start up slowly a locomotive, the brakes of which have been applied, at the point where it is desired to produce the " artificial " load. The starting current is recorded on a suitable recording instrument mounted in the locomotive.

APPENDIX III

INVESTIGATIONS TO BE CARRIED OUT WHEN CASES OF CORROSION IN TELECOMMUNICATION CABLES ARE DISCOVERED

A. 3. 1. — NECESSARY DOCUMENTS

393 The authority in charge of the investigation should assemble the following plans, if possible all to the same scale :

1) plan of the telecommunication cables in the area being considered, with indications of their types and manner of installation ;

2) plan of the electric traction network, with the positions of substations, feeders, track crossings or other special features, such as tracks on bridges or metal structures ;

3) plan of any direct current distribution system (sub-stations, ducts, etc) ;

4) plan of any other cables or metallic pipes (water, gas, electricity, etc.) which may play a part in the exchange of stray current.

394 It is also necessary to collect facts relating to methods of protection already applied.

395 In addition, it is desirable to collect the following information relative to the electric traction network : polarity of the contact line, existence or not of earth electrodes at sub-stations, nature of the rails, the track (buried rails, rails on sleepers etc.), state of the joints, existence of independent feeding sections, output of sub-stations, capacity of feeders, the parts of the system carrying the greatest and the least loads, duration of service, any changes effected at various times to the feeding conditions, etc.

396 Also data on former cases of electrolysis should be collected over a large area including that under immediate consideration : the positions of these cases should be recorded on a map kept readily available.

A. 3. 2. — PRELIMINARY MEASURES OF INVESTIGATION

397 The object of these measurements is :

1) to determine if stray currents exist which would be likely to have caused the corrosion damage observed ;

2) if such is the case, to discover which traction or power supply system may be the cause ;

3) to determine, by simple means, the conditions of exchange of stray current between the cables, pipes or traction lines concerned and the earth, in order to decide, as far as possible, if these arise from the normal operation of the system producing the stray currents, or from a fault condition which it will be necessary to remedy at once.

398 These investigations are carried out by means of different measurements which will be described separately, although it is often necessary to carry out several of them simultaneously.

399 Certain of the measurements involve the connection of apparatus to the traction rails. The measurements should not be carried out without taking precautions against adversely affecting the running of the system ; it is therefore desirable to carry them out by agreement with the authority controlling the system.

A. 3. 2. 1. — *Measurement of differences of potential between the cable and the earth.*

400 These measurements should be taken near the points where corrosion has occurred and also extended further afield.

401 In general, abrupt and frequent variations in the voltage indicate an interchange between the cable and earth of stray currents arising from a traction system, or less likely, from a direct current distribution system.

402 When the cable is distinctly positive with respect to the earth electrode, this indicates that current is leaving the cable and entering the soil. Conversely when the cable is distinctly negative to the earth electrode, this indicates that current is entering the cable.

403 When using an earth electrode, consisting of a metal mass or metal spike a distinct measurement is one in which the readings exceed one volt (in one direction or the other).

404 A more precise measurement can be obtained by using an electrode of the same material as the cable sheath.

405 Measurements of the highest precision with non-polarisable electrodes are not necessary for preliminary investigations.

A. 3. 2. 2. — *Measurement of current in the cable sheath.*

406 When circumstances allow, the current flowing in the cable sheath is measured. Comparison of readings taken at relatively close points, such as successive jointing chambers may allow the section to be determined where current enters or leaves the sheath.

A. 3. 2. 3. — *Measurement of fall in potential along a cable.*

407 Simultaneous measurements of the fall in potential at points along cables are made with the object of determining where current enters or leaves the cables. Such measurements should be carried out where electrolytic corrosion has occurred. It may be informative to extend the measurements until places are found where the direction of the exchange of current between the cables and the earth is opposite to the direction originally observed. It is desirable to make measurements where large exchanges of current with the earth, in one direction of the other, are suspected.

408 These measurements are most conveniently made on cable lengths of about 100 to 150 metres (the distance between two jointing chambers). Maximum information is obtained if between the points of attachment of the apparatus, the cable is free from contact with other cables or metal pipes and if, in successive measurements, there is the same value of resistance between the points of attachment, or at least a value of resistance proportional to their spacing (this latter condition is met if in the area under consideration the cable sheath is uniform).

409 When there are several cables not insulated from each other, (as for example in a single duct), it is desirable to treat all the sheaths as one conductor by bonding them together where the test leads are attached. Measurements cannot be made between two points if a cable branches off between them.

410 If these conditions are observed, sound deductions can be drawn from the measurements referred to above. They indicate, in fact, the direction, and with a fair degree of accuracy, the average value, in the section studied, of the current flowing in the cable sheath. By carrying them out simultaneously on consecutive cable lengths and noting differences, it is possible to deduce the direction and the magnitude of currents exchanged between the cable and the earth.

411 If, for example, at the ends of a particular length, the falls in potential measured correspond to diverging or converging currents there is pick up or loss of current in the length. Similar conclusions can be drawn if on either side of a section the falls in potential are in the same direction but different in value.

412 It is necessary to take measurements over a sufficiently long period for it to be possible to compare average values.

A. 3. 2. 4. — *Tracing the system from which the stray currents originate.*

413 This is done by comparing the electrical conditions of the cable sheaths in the area concerned, both when all the systems suspected are in use and again when, on one or more of them, the service is shut down for a defined period.

414 1) Let the case be considered of a direct current electric traction system, and a direct current power distribution system in the same locality.

415 A series of measurements will first be made by day during the service of the traction system : a graph of the variations over a quarter of an hour (this duration to cover at least one circulation on the lines where the passing of cars is infrequent), and under the conditions indicated in pars. A. 3. 2. 3. and A. 3. 2. 1, of the fall in potential on a selected length of cable or the difference of potential between the cable and earth, should be drawn.

416 Simultaneously, recordings should be made, under similar conditions, of variations in the potential difference existing between the rails and an earth electrode close to the point where the preceding measurements were taken.

417 A second series of measurements will next be carried out under the same conditions, but after (if possible several hours after), the traction service has been shut down.

418 If, in the second series of tests, the fall in potential observed along the cable is almost negligible or much lower than the average of those in the first series, the electric power distribution system may be eliminated, as not being concerned.

419 If the opposite is the case there may be some doubt.

420 On the other hand, if in the first series of tests the fall in potential along the cable, or the potential difference between the cable and earth show abrupt variations simultaneously which are more or less proportional to the variations in potential difference betwen the track and the earth, the conclusion may be drawn that the electric traction system is definitely concerned.

421 2) When there are in the same locality two electric traction systems and a direct current power distribution system and it is possible to make observations when service on the two traction systems is shut down, similar deductions may be made as to whether or not the power distribution system is involved.

422 When there are two traction systems, one in which service is shut down during a part of the night, and the other where there is a continuous service (as is likely in the case of a railway), tests are carried out when service on the former is shut down and when there is movement of trains on the latter. If there is no abrupt variation in the fall of potential along the cable, or in the difference of potential between the cable and the earth during the movement of trains, it may be presumed that the second system is not involved. If, on the other hand, there are variations corresponding to the movement of trains but of a very much smaller magnitude than the variations observed during the day, it may be recognised provisionally that the greater part of the stray current in the area under consideration originates from the system on which service is shut down at night and tests may be continued as if it were alone concerned.

A. 3. 2. 5. — *Determination of the areas in which current flows from the rails to the earth, and those in which current from the earth enters the rails.*

423 This investigation should be made when it has been established that the electrolytic corrosion experienced can be attributed to the operation of a traction system.

424 It can be made by measuring the difference in potential between sections of the rail system, and sections of the underground cables, metal pipes etc., in the neighbourhood (as for example telecommunication cables and water pipes).

425 In order to avoid excavation, the measuring apparatus is connected between the rail and an accessible metallic part (a junction box, or stop-cock, etc.).

426 When the average of the readings taken at one point, over a period of ten minutes, shows the rails to be distinctly positive with respect to the neighbouring metallic pipe systems, it is highly probable that at this point stray current flows from the rails into the soil.

427 On the other hand, it may also be assumed that leakage of current on to the sheaths of the telecommunication cables takes place in localities where the cables are distinctly negative with respect to the track, and that emergence of current takes place where the cables are distinctly positive.

428 A distinct measurement is one where the average of the readings exceeds one volt.

429 The foregoing measurements should be made at points about 100 to 200 metres apart where there has already been electrolysis, or where there is reason to suspect a large interchange of current between the cable and the earth. They should be extended on each side of these points as far as may be necessary to discover the areas in which the exchange of current between the track and the earth changes in direction from that first observed.

430 The picture given by these results may be completed or made more precise in so far as the exchange of current between the cables and the earth is concerned, by carrying out at selected points the tests referred to in paragraphs A. 3. 2. 1. and A. 3. 2. 3.

A. 3. 2. 6. — *General interpretation of the foregoing measurements.*

431 The measurements just described when considered together allow the areas in which there are exchanges of stray current with the earth to be determined.

432 When there is concentration of stray current in a relatively restricted area, one should try to discover if there is a fault condition in the area which should be remedied as a matter of urgency (bad condition of the track, broken fishplate, poor bonding connections on the track at such points as crossings and moving bridges, etc., insulation defects or defects in the continuity of return feeders or in their connections to the rails, chance contact of the track or telecommunication cables with buried metal structures).

433 When the stray currents vary in a sensibly continuous manner along the length of the track or the pipe system, it may be assumed that the effects observed depend on the general disposition of the system producing the stray currents and that an improvement can only be expected from rearrangement of the whole system.

A. 3. 3. — COMPLEMENTARY STUDY

434 If the preliminary investigations described do not trace the origin of the stray currents giving rise to the corrosion, or if they are not sufficient for determining the remedies, a complementary investigation should be undertaken by specialists with more ample measuring equipment at their command.

APPENDIX IV

THE APPLICATION OF ELECTRIC PROTECTION

A. 4. 1. — GENERAL

435 To ensure the electric protection of a metallic structure buried or immersed, it must be made sufficiently negative with respect to the surrounding medium.

The value generally used for lead is -0.55 volts, when measured to a copper sulphate electrode. For iron the corresponding value is -0.85 volts.

436 It is not possible to fix a rigid method for the steps to take, with a view to the application of electric protection. In fact, conditions vary greatly according to the magnitude of the stray currents, the nature of the soil, the longitudinal conductance of the cable or pipe to be protected, the presence of and the quality of the protective covering and the existence of other buried cables or pipes.

437 In general, the installation of a scheme of electric protection has the three following successive phases :

1) the preliminary study of the ground through which the pipes or cables to be protected are laid or will be laid (resistivity, potential gradient,...)

2) The making of special tests to determine the practical method of the application of electric protection and the determination of the precise scheme of protection, testing the efficacy of the protection applied, and adjusting the distribution of the potentials and currents.

3) The adoption of complementary arrangements having regard to the presence of other nearby structures.

A. 4. 2. — PRELIMINARY CONSIDERATIONS

438 It is generally useful to prepare a diagram showing the average and the maximum values of the differences of potential between the rails of the electric traction system and the earth. It is also necessary to collect sufficiently complete information on the power feeding and return arrangements of the system.

439 If the protection of an existing underground system is under consideration, it is desirable to prepare a diagram showing the differences of potential between different points on the said system and the earth (see Appendix II).

440 These preliminary measurements will eventually be completed by measurements of the differences of potential between nearby buried structures.

441 Finally, the important resistances between the rail system and the underground system and between nearby underground systems, will be measured.

442 The preliminary study thus made leads firstly to the determination of :

1) sections of cables or ducts to be protected which must be insulated from certain important metallic structures (bridges, frameworks...) ;

2) branching cables or ducts which must be insulated from the main system to be protected ;

443 and secondly, to the preparation of a programme of tests, arranged with a view to bringing the electric protection scheme into use, i.e. :

1) the establishment of one or more connections between the cable or duct to be protected and the traction system,

2) the installation of connections between nearby underground systems.

A. 4. 3. — TESTS OF DRAINAGE OR FORCED DRAINAGE

444 These tests generally include recordings over 24 hours of :

1) the difference in potential between rails and underground systems close to each point selected for the installation of a drainage connection ;

2) the magnitude of the current flowing in each of the drainage connections.

445 The instrument records indicate the maximum value of current in the direction of drainage and in the reverse direction. A planimeter may be used to obtain the average value.

446 During the recording of the flow of current in the drainage connection, readings of the differences of potential between the cable or duct systems and the earth are taken at different points, so as to fix the approximate average minimum values of the current drained which will ensure suitable protection over most of their length of the cables or ducts to be protected.

447 The successive readings of the difference of potential and the short-circuit current at the different points chosen, permit the fixing directly for them of the apparent resistances between the rails and the underground system.

448 If reversals of the direction of the current are recorded in one or more drainage connections it is useful to insert a unidirectional device (polarised drainage), unless only very rare reversals of short duration, and having a low intensity of current, are concerned.

449 When protection is not ensured over the whole of the length of the cables or ducts to be protected, other arrangements must be made, such as either an increase of the number of drainage connections, or the replacement of one or more drainage connections by forced-drainage.

450 If, bearing in mind the desired result, the current in a drainage connection is too high, a suitable resistance is connected in circuit.

451 In order to make a forced drainage test, a high capacity battery is inserted in the drainage connection, and the same recordings and readings are taken as above, by successively inserting in the drainage connection different electromotive forces viz. 2 volts and 4 volts.

452 The measurement of potential (with respect to the earth) of cables or ducts to be protected allows the exact predetermination of the characteristics of the forced-drainage apparatus in order to ensure a suitable distribution of the protection potential.

453 However, if it is impossible to find favourable points of access on the rails for the drainage connections, which do not have too high a potential, it is possible to abandon the use of rails as anodes and to have recourse (in spite of the higher resistance to the flow of current to the earth) to independent anodes placed at judiciously chosen points.

454 To improve the distribution of protection potential along the cables or ducts to be protected, in certain cases the insertion of some resistance joints at appropriate points on the cables or ducts may be considered.

A. 4. 4. — PROTECTION CONNECTIONS BETWEEN UNDERGROUND CABLE OR DUCT SYSTEMS

455 It is frequently useful to extend the electric protection to neighbouring structures by joining them by special connections to directly protected cables or ducts. A simple graphical method enables the resistance of these protection connections to be determined taking into account primarily the different nature of the metals of which the structures consist.

456 Sometimes it is necessary to insert one or more rectifiers into these connections when appreciable reversals of current are noted in them. In such cases it is necessary to take into account the characteristic of the rectifiers when determining the resistance of the protection connections.

457 It is also possible that it may become necessary to insert an inductance coil in the protection connection if it is desired to avoid the flow of alternating currents, which might damage the rectifiers or the telecommunication cables.

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