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Railway applications — Fixed installations — Electrical safety, earthing and the return circuit

Part 2: Provisions against the effects of stray currents caused by d.c. traction systems

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National foreword

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The UK participation in its preparation was entrusted to Technical Committee GEL/9/3, Railway Electrotechnical Applications - Fixed Equipment.

A list of organizations represented on this committee can be obtained on request to its secretary.

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**Railway applications -
Fixed installations -
Electrical safety, earthing and the return circuit -
Part 2: Provisions against the effects of stray currents caused by d.c.
traction systems**

Applications ferroviaires -
Installations fixes -
Sécurité électrique, mise à la terre et
circuit de retour -
Partie 2: Mesures de protection contre les
effets des courants vagabonds issus de la
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Bahnanwendungen -
Ortsfeste Anlagen -
Elektrische Sicherheit, Erdung und
Rückleitung -
Teil 2: Schutzmaßnahmen gegen
Streustromwirkungen durch Gleichstrom-
Zugförderungssysteme

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European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

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Foreword

This European Standard was prepared by SC 9XC, Electric supply and earthing systems for public transport equipment and ancillary apparatus (Fixed installations), of Technical Committee CENELEC TC 9X, Electrical and electronic applications for railways. It was submitted to the formal vote and was approved by CENELEC as EN 50122-2 on 2010-10-01.

This document supersedes EN 50122-2:1998 + A1:2002.

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The following dates were fixed:

- latest date by which the EN has to be implemented
at national level by publication of an identical
national standard or by endorsement (dop) 2011-10-01
- latest date by which the national standards conflicting
with the EN have to be withdrawn (dow) 2013-10-01

This draft European Standard has been prepared under a mandate given to CENELEC by the European Commission and the European Free Trade Association and covers essential requirements of EC Directives 96/48/EC (HSR), 2001/16/EC (CONRAIL) and 2008/57/EC (RAIL). See Annex ZZ.

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1 Scope

This European Standard specifies requirements for protective provisions against the effects of stray currents, which result from the operation of d.c. traction systems.

As experience for several decades has not shown evident corrosion effects from a.c. traction systems and actual investigations are not completed, this European Standard only deals with stray currents flowing from a d.c. traction system.

This European Standard applies to all metallic fixed installations which form part of the traction system, and also to any other metallic components located in any position in the earth, which can carry stray currents resulting from the operation of the railway system.

This European Standard applies to all new d.c. lines and to all major revisions to existing d.c. lines. The principles may also be applied to existing electrified transportation systems where it is necessary to consider the effects of stray currents.

It provides design requirements to allow maintenance.

The range of application includes:

- a) railways,
- b) guided mass transport systems such as:
 - 1) tramways,
 - 2) elevated and underground railways,
 - 3) mountain railways,
 - 4) trolleybus systems, and
 - 5) magnetically levitated systems, which use a contact line system,
- c) material transportation systems.

This European Standard does not apply to:

- d) mine traction systems in underground mines,
- e) cranes, transportable platforms and similar transportation equipment on rails, temporary structures (e.g. exhibition structures) in so far as these are not supplied directly from the contact line system and are not endangered by the traction power supply system,
- f) suspended cable cars,
- g) funicular railways.

This European Standard does not specify working rules for maintenance.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 50122-1:2010, *Railway applications – Fixed installations – Electrical safety, earthing and the return circuit – Part 1: Protective provisions against electric shock*

EN 50122-3:2010, *Railway applications – Fixed installations – Electrical safety, earthing and the return circuit – Part 3: Mutual interaction of a.c. and d.c. traction systems*

EN 50162:2004, *Protection against corrosion by stray current from direct current systems*

EN 50163, *Railway applications – Supply voltages of traction systems*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 50122-1:2010 apply.

4 Identification of hazards and risks

D.C. traction systems can cause stray currents which could adversely affect both the railway concerned and/or outside installations, when the return circuit is not sufficiently insulated versus earth.

The major effects of stray currents can be corrosion and subsequent damage of metallic structures, where stray currents leave the metallic structures. There is also the risk of overheating, arcing and fire and subsequent danger to persons and equipment both inside and outside the railway or trolley bus system.

The following systems, which can produce stray currents, shall be considered:

- d.c. railways using running rails carrying the traction return current including track sections of other traction systems bonded to the tracks of d.c. railways;
- d.c. trolleybus systems which share the same power supply with a system using the running rails carrying the traction return current;
- d.c. railways not using running rails carrying the traction return current, where d.c. currents can flow to earth or earthing installations.

All components and systems which can be affected by stray currents shall be considered such as:

- running rails,
- metallic pipe work,
- cables with metal armour and/or metal shield,
- metallic tanks and vessels,
- earthing installations,
- reinforced concrete structures,
- buried metallic structures,
- signalling and telecommunication installations,
- non-traction a.c. and d.c. power supply systems,
- cathodic protection installations.

Any provisions employed to control the effects of stray currents shall be checked, verified and validated according to this European Standard.

The system design shall be completed sufficiently early that the results can be taken into account in the essential system parameters, which influence the stray current effects, like the spacing of the substations and in the design of the civil structures, see also 5.4.

The entity responsible for the design and erection of the railway infrastructure shall make sure that electrical requirements for railway related civil structures are met.

In case of major revisions of existing lines the effects on the stray current situation shall be assessed by calculation and/or by measurements.

If stray current provisions affect electrical safety, protective provisions against electric shock according to EN 50122-1 shall take precedence over provisions against the effects of stray currents.

5 Criteria for stray current assessment and acceptance

5.1 General

The amount of stray currents and their effects depend on the overall system design of the traction power supply. Stray currents leaving the return circuit can affect the return circuit itself and neighbouring installations, see Clause 4.

Beside to the operating currents, the most important parameters for the amount of stray current are:

- the conductance per length of the tracks and the other parts of the return circuit,
- the distance of the substations,
- the longitudinal resistance of the running rails,
- spacing of cross bonds.

If the railway system meets the requirements and measures of this European Standard, the system is assumed to be acceptable from the stray current point of view.

5.2 Criteria for the protection of the tracks

The most important influencing variable for stray currents leaving the tracks is the conductance per unit length between track and earth. The corrosion rate is the main aspect for the assessment of risk.

The rail potential provides the main information about the relevant parameters, which represent the stray currents. These parameters are the traction currents, the longitudinal resistance of the running rails, the resistance to earth and the length of the feeding sections. The precondition for this proceeding is that there is no direct electrical connection either accidental or intended to earthing installations.

Experience proves that there is no damage in the tracks over a period of 25 years, if the average stray current per unit length does not exceed the following value:

$$I'_{\max} = 2,5 \text{ mA/m}$$

(average stray current per length of a single track line).

NOTE 1 For a double track line the value for the maximum average stray current should be multiplied by two. For more than two tracks the value increases accordingly. For the averaging process, only the total positive parts of the stray current over 24 h or multiples are considered.

If the following values for the conductance per length G'_{RE} and average rail potential U_{RE} are not exceeded during the system life-time, further investigations according to 5.4 need not be performed.

$$- \quad G'_{\text{RE}} \leq 0,5 \text{ S/km per track and } U_{\text{RE}} \leq + 5 \text{ V} \quad \text{for open formation} \quad (1)$$

$$- \quad G'_{\text{RE}} \leq 2,5 \text{ S/km per track and } U_{\text{RE}} \leq + 1 \text{ V} \quad \text{for closed formation} \quad (2)$$

For the average rail potential shift U_{RE} only positive values of the rail potential are considered. The averaging period shall be 24 h or multiples.

NOTE 2 A guide value for the sampling rate is 2 per second.

If the requirements in Equations (1) and (2) are not met, an alternative value for G'_{RE} shall be calculated and used for the design, applying Equation (3).

$$G'_{RE} = \frac{I}{U_{RE}} \quad (3)$$

where

$$I' = 2,5 \text{ mA/m per track or the value coming from the investigation in 5.4.}$$

NOTE 3 For a double track line the value for the maximum conductance per length should be multiplied by two. For more than two tracks the values increase accordingly.

NOTE 4 As it is not easy to measure the stray currents directly, the measurement of the rail potential is a convenient method. According to Equation (3), the acceptable conductance per length can be calculated for a single track line.

NOTE 5 Simulation of the traction power supply for scheduled train operation can provide values for the stray current per length for design purposes. A method of calculating dead-end tracks is given in Clause C.1. This is a conservative method, because the actual values are lower.

When the construction phase has been completed, it shall be proven that the permissible conductance per length according to Equations (1), (2) or (3) is fulfilled. Annex A indicates proven methods for the measurement.

During operation, compliance with the limits of conductance per length according to Equations (1), (2) or (3) shall be maintained.

5.3 Criteria for systems with metal reinforced concrete or metallic structures

In systems with metal reinforced concrete or metallic structures, like:

- reinforced track bed,
- tunnels, or
- viaducts,

the impact on the structures shall be considered.

The voltage shift of the structure versus earth is an additional criterion for assessment.

Experience has shown, that there is no cause for concern, if the average value of the potential shift between the structure and earth in the hour of highest traffic does not exceed + 200 mV for steel in concrete structures. For buried metal constructions the values depend on soil resistivity and the material. For both requirements refer to EN 50162:2004, Table 1.

In order to avoid inadmissible stray current effects at the tunnel structure and at structures outside of the tunnel, the longitudinal voltage between any two points of the through connected metal reinforced tunnel structure should be calculated. The maximal longitudinal voltage shall be smaller than the permissible potential shift. As an example for calculation see C.2. This is a conservative procedure which ensures that the actual values for the tunnel potential against earth will be lower.

5.4 Specific investigations and measures

If the requirements stated in 5.2 and 5.3 are not achieved, or if other methods of construction are planned, a study shall be carried out at an early planning stage. The study becomes also necessary in case of major revisions of existing lines, when the stray current situation is likely to become worse.

The possible impact of stray current corrosion shall be investigated, where the following aspects are included, such as:

- insulation from earth of the rails and connected metallic structures,
- humidity of the track bed,
- longitudinal resistance of the running rails,
- number of and distance between the substations,
- effects of inequalities in the no load voltages of substations,
- substation no-load voltage and source impedance,
- timetable and vehicles,
- neighbouring metallic structures.

Clause 6 and Clause 7 show suitable corrective provisions.

6 Design provisions

6.1 General

Any provisions employed to control the effects of stray currents shall be checked, verified and validated according to this European Standard.

The system design shall be completed sufficiently early that the results can be taken into account in the essential system parameters which influence the stray current effects, like the spacing of the substations and the design of the civil structures.

6.2 Return circuit

6.2.1 General

In order to minimise stray current caused by a d.c. traction system, the traction return current shall be confined to the intended return circuit as far as possible.

As the return circuit in case of d.c. traction systems usually is not connected to earth, safety requirements for the rail potential according to EN 50122-1:2010, 6.2.2 and Clause 9, shall be fulfilled.

6.2.2 Resistance of running rails

The longitudinal resistance of the running rails shall be low. Therefore, rail joints shall be welded or connected by rail joint bonds of low resistance such that the longitudinal resistance of the rails is not increased by more than 5 %.

The longitudinal resistance can be reduced by the use of rails with greater cross section and/or cross bonding of the running rails and/or the tracks where signalling considerations allow.

6.2.3 Track system

A high level of insulation from earth of the running rails and of the whole return circuit is required, when the running rails are used as part of the return circuit.

The track shall be so designed that the insulation quality of the rails toward earth will not be diminished substantially by water. In order to fulfil the values given in Equations (1), (2) and (3) of 5.2 the water drainage of the substructure of the running rails is essential.

NOTE 1 The values given for the conductance per length apply to a track consisting of two running rails with tie bars as well as the attached system parts.

NOTE 2 The following provisions can be made to achieve the required values of the conductance G'_{RE} for rails laid in an open formation:

- clean ballast;
- wooden sleepers or reinforced-concrete sleepers with insulating fastening;
- distance between running rails and ballast.

NOTE 3 The following provisions can be made to achieve the required values of the conductance G'_{RE} for rails laid in a closed formation:

- fitting of the running rails in an insulating resin bed;
- provision of insulating intermediate layers between the tracks and the bearing systems;
- effective drainage.

6.2.4 Return conductors

Return conductors, if required, are laid in parallel to the running rails and shall be connected to them at regular intervals. They shall be insulated from earth.

6.2.5 Return cables

Return cables connect the running rails with the substation. They shall have an insulating outer sheath, so that no stray currents can leave or enter.

NOTE Where mechanical damage is likely, return cables should have an additional protection.

6.2.6 Electrical separation between the return circuit and system parts with earth-electrode effect

In order to reduce stray currents, no part of the return circuit shall have a direct conductive connection to installations, components or metallic structures which are not insulated from earth.

NOTE In case of direct conductive connection to installations, components or metallic structures which are not insulated from earth, the values given in Equations (1), (2) and (3) of 5.2 should be fulfilled for the return circuit and parts connected to it.

If a connection to the return circuit is unavoidable for reasons of protection against electric shock, provisions shall be taken to reduce the stray current effects. These can be for example:

- open connection with the return circuit, in this case the voltage-limiting device shall satisfy the requirements given in EN 50122-1:2010, Annex F;
- insulation of the equipment or components that are connected to the running rails, from foundations or components that are earthed;
- insulation of the metal reinforcement of the structure from earth.

For exceptions regarding workshops and similar locations see Clause 9.

A conductor rail insulated from earth, the so-called "fourth rail", can be used for the traction return current. If this is a live part and not connected to the running rails, usually no stray currents occur. In the case of conductor rail systems with third and fourth rails, each conductor rail shall be insulated from earth depending on the nominal voltage of the system according to EN 50163.

6.2.7 Rail-to-rail and track-to-track cross bonds

Rail-to-rail cross bonds, tie bars, track-to-track cross bonds and other bonds which can come in contact with earth shall be insulated.

6.3 Non-traction related electrical equipment

Non-traction related electrical equipment shall be installed according to EN 50122-1:2010, Clause 7.

6.4 Tracks of other traction systems

Generally, the tracks of other traction systems shall not have any direct conductive connection to tracks of d.c. traction systems.

Tracks without contact line may be connected to the return circuit in special cases if they fulfil the requirements given in 6.2.3.

If running rails are used by d.c. and a.c. traction systems, additional provisions shall be made against the stray current hazard and against impermissible touch voltages, see EN 50122-3.

Any additional provisions shall not affect other safety criteria, particularly such that are made to minimise the touch voltage as well as such that are made to operate the power supply, track circuits and communication systems.

6.5 Return busbar in the substation

The substation shall be arranged so that direct current does not flow in the substation structure earth. Risks from stray current relating to the earthing of equipment due to maintenance work shall be taken into account. The return busbars in substations and similar installations shall be operated so that they are insulated from earth. Where required for safety reasons a voltage-limiting device (minimum type O) to connect between the return busbar and earth shall be provided in accordance with EN 50122-1:2010, Annex F. For substations in depots and workshops see Clause 9.

6.6 Level crossings

At level crossings, where the running rails are laid in a closed formation, care shall be taken that the value of the conductance per length does not exceed the value of the neighbouring tracks.

6.7 Common power supply for tram and trolleybus

If trolleybuses and tramways receive their traction power from the same substation, one of the trolley contact wires may be connected with the track return system referred to EN 50122-1. In this case it shall be checked to determine whether the protective provisions for both systems to minimise stray current effects are still sufficient.

The insulation of the running rails shall be coordinated with other provisions ensuring that acceptable touch voltages according to EN 50122-1 are not exceeded during operation, in case of a short-circuit and in case of an earth fault.

6.8 Changeover from the mainline to depot and workshop areas

See Clause 9.

7 Provisions for influenced metallic structures

7.1 General

The resistance between conductive structures which are not insulated from earth and the track return system shall be high. Except in the case of depots and workshops (see Clause 9) earth and track return systems shall not be connected directly. A direct connection to earth may also be allowed in certain industrial systems with d.c. traction taking into consideration the particular surrounding conditions, e.g. open cast coal mines.

7.2 Tunnels, bridges, viaducts and reinforced concrete slab track

7.2.1 Basic proceeding

In a tunnel structure which incorporates conductive components it can be necessary to make provisions to limit possible effects of stray currents. The requirements for protection against electric shock shall be taken into account. This is also applicable to viaducts, bridges and reinforced concrete slab tracks.

NOTE The provisions to reduce the stray current effects in tunnel structures with conductive components can depend on:

- whether the predominant source of the stray current is internal or external to the tunnel,
- whether the main priority is to protect the tunnel metallic structures, or to protect other metallic structures external to the tunnel and the railway.

7.2.2 Longitudinal interconnection

In the case of tunnels with metal reinforced concrete structures or other conductive structures it is possible that stray currents can flow into such structures and from there cause influence to other conductive structures outside the tunnel. In this case the effect of such influence shall be reduced by means of equipotential bonding in the lower part of the individual tunnel sections or other conductive structures to achieve the voltage requirements according to 5.3. This equipotential bonding shall be achieved by:

- a sufficient number of reinforcing bars,
- mats connected together,
- other conductive structural parts,
- if necessary, additional conductors of appropriate cross section laid within the tunnel.

Individual tunnel sections in particular cases may be excepted from the equipotential bonding of the rest of the tunnel. The equipotential bonding of the other tunnel sections can be achieved by means of an insulated cable extending over the segregated tunnel section.

NOTE For stray current protection purposes only, it is possible to achieve adequate electrical conductivity of reinforcing bars within a structure section by means of conventional steel wire wrapping.

7.2.3 Sectionalized reinforcement

In areas where the influence of stray currents on structures outside the tunnel is not significant and when a sufficiently high value of rail to earth resistance cannot be achieved, e.g. due to humidity or ballast which is not sufficiently clean, the main consideration shall be the corrosion of the tunnel metallic structures.

Reinforced concrete tunnel structures shall be divided into longitudinal sections by insulating joints in the case where stray currents from other adjacent systems can flow along the tunnel structure, thus causing an undesirable electrical connection between different areas.

NOTE 1 If the resistance between these structures and earth is relatively high, for example in rock tunnels, the reinforced concrete tunnel structures may also be divided into longitudinal sections by insulating joints.

If there is any risk of an impermissible voltage between simultaneously accessible parts, refer to EN 50122-1.

At ring joints between each section, terminals shall be provided for test purposes. A reliable electrical connection shall be made between these terminals and the longitudinal reinforcing bars.

NOTE 2 Normally, no connection will be made between the terminals of adjacent sections.

7.2.4 External conductive parts

The reinforcement of steel-reinforced concrete tunnels and tunnel components consisting of conductive materials shall not have any electrical connection to pipes and cables located outside the tunnel or to the return circuit or to any adjacent systems which are not insulated from earth. If this electrical separation is not possible, for instance due to different earthing systems being present in one building danger of stray current exchange and in consequence danger of stray current corrosion exists. In this case continuous monitoring, shall be provided, see 10.2.1, and rail to structure earth connections shall be removed promptly.

Connections of the tunnel reinforcement to additional earthing systems are permissible in order to satisfy earthing requirements for protective provisions.

7.2.5 Cables, pipework and power supply from outside

Precautions are necessary in order to avoid possible stray current exchange between structure earth and remote non-railway installations. At the entrance to metal reinforced concrete or metallic railway structures, such as tunnels and viaducts, depots and workshops, all metallic pipe work, hydraulic lines, cable sheaths, and connections to earth, coming from outside shall be separated electrically from the structure earth in order to avoid any conductive connection to external earth electrodes.

NOTE 1 This can be achieved by:

- insulating parts in the pipes or alternatively complete insulation of the pipes from the structure earth,
- installation of transformers with separate windings or by the use of the TT system in accordance with EN 50122-1.

NOTE 2 When necessary for safety reasons, every section of metal pipe may be connected to the structure earth.

7.3 Adjacent pipes or cables

Where d.c. traction systems are close to buried pipes or cables, efforts shall be made to ensure that the conductive parts are kept as far away as practicable to minimise stray current interference.

For the assessment of possible stray current impact the measurement method given in A.4 can be used.

NOTE Experience has shown that for crossings of tracks with pipes or cables a minimum distance of 1 m is adequate for stray current protection purposes.

7.4 Voltage limiting devices

If voltage-limiting devices (VLD) between the return circuit and the metallic components of the structure are provided as a protective provision to prevent impermissible voltages the protective provisions against the effects of stray current shall be satisfied; see EN 50122-1:2010, Annex F.

8 Protective provisions applied to metallic structures

The provisions in this European Standard are intended to reduce stray currents in order to reduce stray current corrosion. Conventional protective provisions against natural corrosion for non-railway installations can be used if they are considered to be necessary. If additional protective methods are taken into account, the overall protection concept shall be agreed with affected parties and comply with the relevant standards concerning stray current corrosion.

NOTE The connection of any metallic structure to return bus bar in a substation even via a polarised electric drainage device will increase the overall stray current. Therefore, the connection of any metallic structure to the return bus bar should be made only with due consideration given to the overall effect on the running rails and other structures which could be influenced. Polarised electric drainage is generally applicable only when the structure to be protected is remote from other structures.

9 Depots and workshops

As the tracks in depots and workshops are concentrated on a small area, no major voltage drop arises in this track area. Therefore, in deviation from the generic requirement in 7.1 a direct connection between the structure earth and the return circuit is tolerable for equipotential bonding for safety reasons. As a consequence of that, the running rails in depots or workshops and similar locations shall be separated from the main line by insulating rail joints and the traction power shall be supplied by separate transformer-rectifier units. Exceptions are allowed provided a stray current study proves no negative effects can occur. For touch voltage across the rail joints see EN 50122-1:2010, Table 6.

If the running rails of the depot and workshop area are connected to the main line, the insulation of the return circuit versus earth shall be the same as on the main line.

NOTE In order to fulfil the safety requirements, voltage-limiting devices (VLD-O) should be installed if necessary. The setting of them shall fulfil the values for depots and workshops according EN 50122-1:2010, 9.3.2.3.

10 Tests and measurements

10.1 Principles

In order to avoid corrosion damage in the return circuit according to 5.2 and damage in neighbouring metallic structures according to 5.3, the stray current situation shall be assessed during commissioning and checked during operation. Corrective measures can then be taken where necessary.

Direct measurement of stray currents is difficult, alternative methods have been proven to be practical. They are based on the measurement of the resistance of the return circuit to earth or the voltage against earth resulting from train operation. Changes in the conductance per length need preferably be investigated and countermeasures shall be started, if required by the stray current situation.

Unintended return circuit to earth connections shall be removed sufficiently early so that significant damage will not be caused by stray current corrosion.

For stray current assessments a recognised method shall be used in certain intervals. Annex A lists appropriate procedures.

10.2 Supervision of the rail insulation

10.2.1 Continuous monitoring of the rail potential

The rail potential along the line changes, when the conductance per length changes significantly, e.g. in case of low-resistive electrical connections between the return circuit and earth.

During operation the rail potential is compared with a reference situation. The reference situation is the situation, in which the system meets the requirements according to this European Standard.

Changes in the rail potential along the line indicate deficiencies in the conductance per length including individual rail-to-earth connections of the return circuit, which can affect the stray current situation.

Continuous monitoring of the rail potential supports the supervision of the continuity of the return circuit, detects connections between the return circuit and earth and pollution of rail fastenings. A recommended method is given in B.1.

10.2.2 Repetitive monitoring

10.2.2.1 General

If a continuous monitoring is not applied, repetitive monitoring shall be carried out.

The time interval for the repetitive inspections shall be fixed depending on the specific risk situation.

NOTE For the repetitive monitoring a period of five years is recommended.

10.2.2.2 Repetitive measurement of the conductance per length of the running rails

The requirements for conductance per length according to 5.2 shall be fulfilled. Proven methods for measurement are given in A.1 to A.5.

10.2.2.3 Repetitive measurement of the rail potential

The rail potential along the line changes when electrical connections between the return circuit and earth arise or when the conductance per length of the running rails changes. Such situations can be detected by measurements, if other influencing parameters, e.g. operation currents and train schedule do not change significantly.

NOTE Successive measurements should preferably use the same locations and methods.

If the repetitive measurement of the rail potential along the line in regular intervals detects deficiencies in the rail insulation, countermeasures shall be started to improve the situation. A recommended method for measurement is given in B.2.

Annex A (informative)

Measurement of track characteristics

A.1 Rail resistance

The measurement of the rail resistance is necessary to obtain the relation between the rail current and the resulting voltage for the subsequent determination of the conductance per length e.g. in a tunnel. Figure A.1 shows the recommended measuring arrangement.

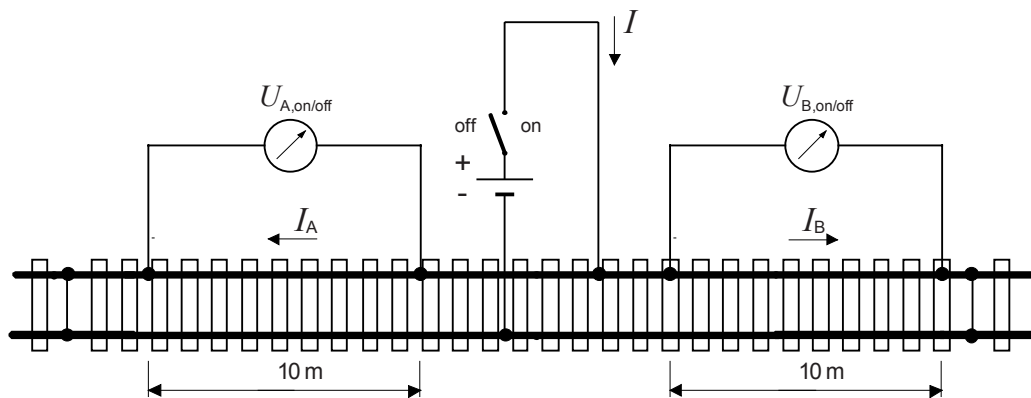


Figure A.1 — Measurement of the rail resistance for a rail of 10 m length

The measuring d.c. current I is periodically to be switched on and off in order to check other effects during the off-period.

Variation of reading values should be taken into account by several measurements. Significant differences resulting from changed polarity of the measuring circuit should be investigated.

The method is valid only if these measurements are performed without any traction current. Where this is not practical, the measurements should be made at the same time in order to eliminate the effect of currents other than the measuring current.

The measuring points at the running rails should be at least 1 m away from the injection points.

The longitudinal voltage drop U_A and U_B is measured for each of the two adjacent sections of rail. The rail resistance is calculated according to the Equation (A.1).

$$R_{R10m} = \frac{(U_{A,on} - U_{A,off}) + (U_{B,on} - U_{B,off})}{I} \quad (A.1)$$

where

I is the injected current, in amperes (A);

R_{R10m} is the longitudinal resistance of a rail section of 10 m of rail 1 in ohms (Ω);

$U_{on, off}$ is the voltage drop in rail 1 in volts (V), with and without injected current.

The measurement assumes that no rail-to-rail crossbonds or track-to-track crossbonds, e.g. impedance bonds, are connected within the measuring area.

A.2 Conductance per length between running rails and metal reinforced structures

During measurement the running rails are to be electrically separated from the running rails outside the area of the metal reinforced structures via insulating rail joints or rail cuts. It is practical in case of tunnels to locate the separation at the transition ramp towards the at-grade tracks.

A special measuring arrangement and measuring sequence allows the measurement of the conductance per length of running rails against metal reinforced structures without the need of additional insulating rail joints in the track area of the structure. The conductance per length G'_{RS} is to be measured in accordance with Figure A.2 and to be calculated in accordance to Equation (A.2), averaging the three measured voltage values.

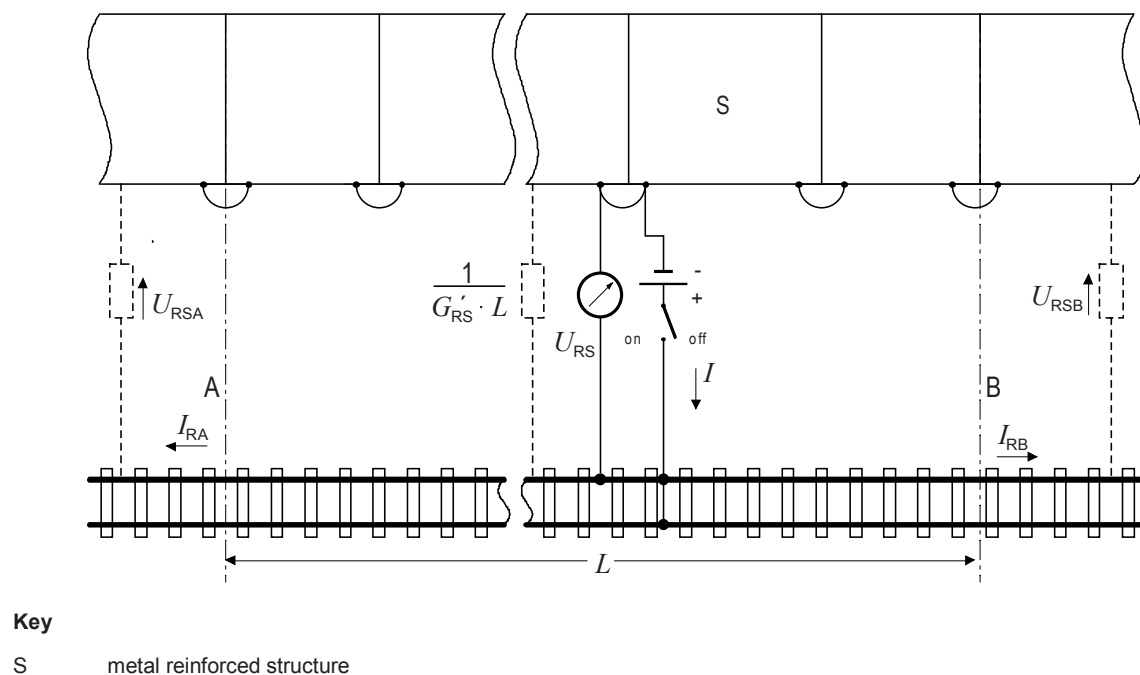


Figure A.2 — Measuring arrangement for the conductance per length G'_{RS} between rails and metal reinforced structure

The measuring d.c. current I , injected between the rails and the structure is to be switched on and off periodically.

$$G'_{RS} = \frac{1}{L} \times \frac{I - I_{RA} - I_{RB}}{(\Delta U_{RS} + \Delta U_{RSA} + \Delta U_{RSB})/3} \quad \Delta U = U_{on} - U_{off} \quad (A.2)$$

where

- G'_{RS} is the conductance per length between rails and structure, in Siemens per kilometre (S/km, with 1 S/km = 1/Ωkm);
- I is the injected current, in amperes (A);
- I_{RA}, I_{RB} is the current flowing beyond the ends A, B of the measured section, in amperes (A);
- U_{RS} is the voltage between the rail and the structure at the point of injection, in volts (V);
- U_{RSA}, U_{RSB} is the voltage between the rail and the structure at the point A, B of the structure, in volts (V);
- L is the length of the section to be measured, in kilometres (km).

The currents I_{RA} and I_{RB} can be gained with help of the voltage drop measurement of the rail described in A.1.

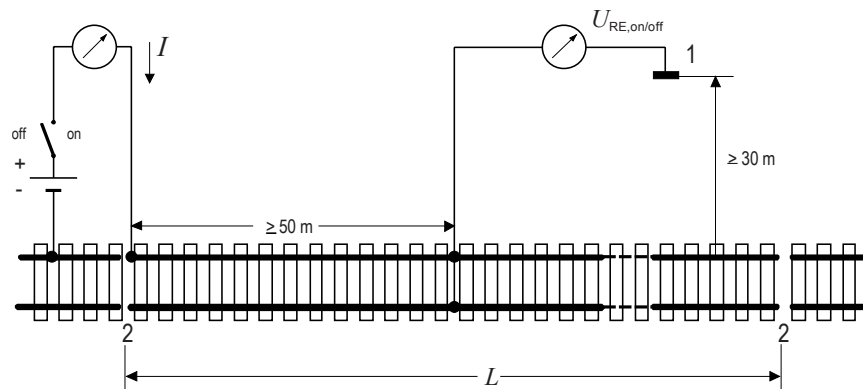
It should be ensured that the measurement are not influenced by rail to earth connections or activated voltage-limiting devices (VLD).

A.3 Conductance per length for track sections without civil structure

The track section to be examined is separated from the continuing lines by insulated rail joints or rail cuts. The length of the track section should not exceed 2 km.

NOTE 1 In case the length of the track section exceeds 2 km, the method of A.4 can be used on locations of interest or insulated rail joints have to be provided in advance.

The conductance per length of the separated track section is determined in accordance with the method shown in Figure A.3 and Equation (A.3).



Key

- 1 reference electrode
- 2 insulating rail joint

Figure A.3 — Determination of the conductance per length G'_{RE} for track sections without civil structures

$$G'_{RE} = \frac{1}{L} \times \frac{I}{U_{RE, on} - U_{RE, off}} \quad (A.3)$$

where

- G'_{RE} is the conductance per length between track and earth in Siemens per kilometre with $1 \text{ S} = 1/\Omega$;
- I is the injected current, in amperes (A);
- U_{RE} is the voltage between the rail and earth;
- L is the length of the section to be measured in kilometres (km).

NOTE 2 Preferably copper/copper sulphate electrodes should be used.

A measuring d.c. current I is injected into the rails at both sides of the insulated rail joints. The current should be periodically switched on and off. The measuring current I flows from the rails of the track section to be examined into the earth and from there into the rails of the connected track section. The voltage between rail and earth U_{RE} and the measuring current is decisive for the determination of the conductance per length. The voltage should be measured using a reference electrode. This electrode is to be placed at least 50 m away from the injection point and at least 30 m away from the track. Additionally rail-to-earth connections, e.g. VLDs shall be checked on correct status in order not to disturb the measurement results.

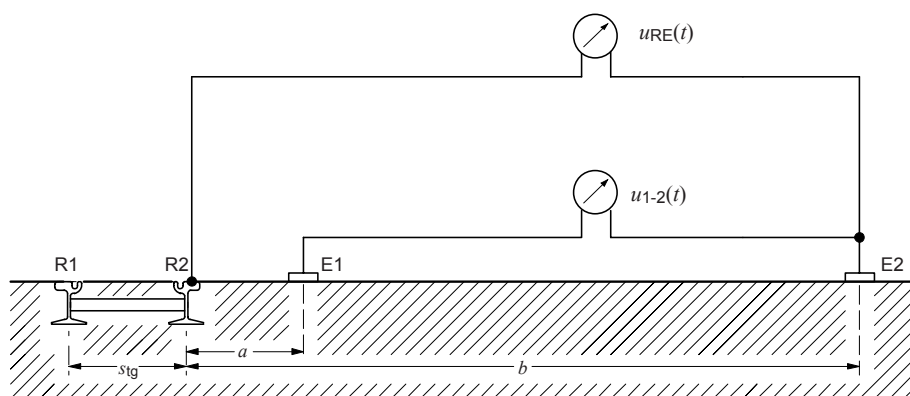
A.4 Local conductance per length for track sections without civil structure

The average conductance per length of an up to 2 km long line above earth is investigated by way of the procedure shown in A.3. In contrast to that the local conductance per length and the stray current influence at the location of measurement can be assessed by way of this method, shown in Figure A.4 and in Equations (A.4) to (A.6). It is not necessary to cut the rails for the measurement. The measurement is performed during operation. The rail potential u_{RE} is registered between the running rails and a reference electrode E2 placed on the earth at a distance b from the running rail R2. The rail potential gradient u_{1-2} is registered by way of a second electrode E1, which is placed at the distance a from the running rail R2, and the remote electrode E2.

NOTE 1 Preferably copper/copper sulphate electrodes should be used.

Both voltages are registered by a data logger. The rail potential gradient ΔU_{1-2} has to be plotted as a function of the rail potential ΔU_{RE} . The slope of the linear regression of this function is the stray current transfer ratio m_{sr} .

Moreover, the soil resistivity ρ_E near the electrode E1 is to be determined.



Key

R1	running rail 1
R2	running rail 2
E1	electrode 1 (close to the rail)
E2	electrode 2 (remote electrode)
$u_{RE}(t)$	rail potential
$u_{1-2}(t)$	voltage between electrodes E1 und E2
a	distance between the rail R2 and electrode E1
b	distance between the rail R2 and electrode E2
s_{tg}	track gauge

Figure A.4 — Measuring arrangement for the local conductance per length

For single-track lines the local conductance per length is calculated as follows:

$$G'_{RE} = \frac{m_{sr} \cdot \pi \cdot 2000}{\rho_E \cdot [\ln(b \times (b + s_{tg})) - \ln(a \times (a + s_{tg}))]} \quad (A.4)$$

To double-track lines the following applies:

$$G'_{RE} = \frac{m_{Sr} \cdot \pi \cdot 1000}{\rho_E \cdot [\ln((b + 0,5 \cdot s_{tg}) \times (b + 0,5 \cdot s_{tg} + s_{td})) - \ln((a + 0,5 \cdot s_{tg}) \times (a + 0,5 \cdot s_{tg} + s_{td}))]} \quad (A.5)$$

where

- G'_{RE} is the local conductance per length between the running rails and earth in Siemens per kilometre (S/km);
- m_{Sr} is the stray current transfer ratio;
- ρ_E is the soil resistivity, in ohm-metres (Ωm);
- a is the distance between the outer running rail and the electrode near the rail, in metres (m);
- b is the distance between the outer running rail and the remote electrode, in metres (m);
- s_{tg} is the track gauge, in metres (m);
- s_{td} is the track distance between centres, in metres (m).

NOTE 2 The components connected directly to the running rails, e.g. water drainage boxes and rail tie bars, can distort the equipotential lines directly next to the rails. Therefore, the distance a should be at least 1 m. The distance b has to be so big that the electrode is outside of the voltage gradient. For this kind of measurements, usually a distance of 30 m is sufficient in urban areas. During measurement it should be checked whether the distance b is sufficient or should be increased. To assess whether the insulation of the running rails is sufficient, measurements should be made at several locations, especially at crossings with other buried installations.

The stray current transfer ratio m_{Sr} is also suited for the regular assessment of the insulation of the running rails towards the earth. If the insulation of the running rails has changed, the stray current escaping into the earth changes to the same extent as the rail potential gradient.

In case that the two preconditions are fulfilled:

- the electrode close to the rail shall be placed at a distance from the running rails that corresponds to the distance of parallel or crossing metallic installations,
- the measurement period shall correspond to a multiple of the timetable cycle,

the root-mean-square value of the changes in rail potential gradient corresponds to the highest possible potential shift of the metallic installations. The root-mean-square value of the changes in rail potential gradient is proportional to the stray current activity U_{SCA} .

$$U_{SCA} = \sqrt{\frac{1}{n} \sum_{i=1}^n (U_{1-2,i} - \overline{U_{1-2}})^2} \quad (A.6)$$

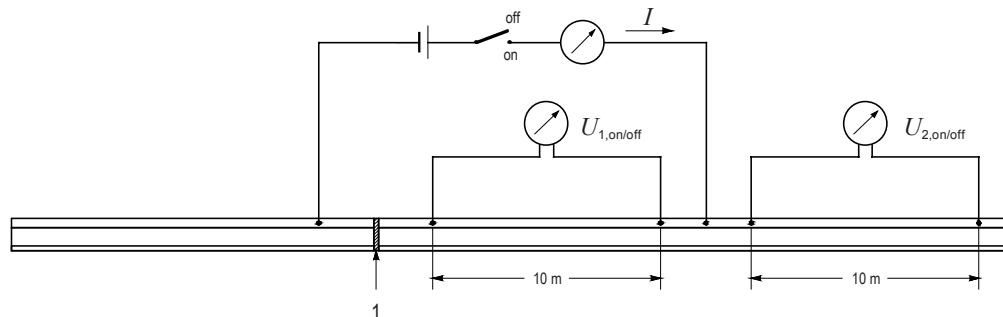
where

- U_{SCA} is the stray current activity of the potential gradient in volts (V);
- n is the number of the measured data;
- $U_{1-2,i}$ is the instantaneous value of the potential gradient in volts (V);
- $\overline{U_{1-2}}$ is the average of the potential gradient in volts (V).

The assessment is made as described in EN 50162:2004, Table 1. If the stray current activity exceeds the permissible value mentioned in EN 50162, it might be necessary to perform long-time measurements over 24 h and to assess the positive potential shift of the metallic structure.

A.5 Insulating rail joints

Figure A.5 shows the measuring arrangement for the testing of an insulated rail joint of a rail. It has to be ensured that no rail-to-rail cross bonds and track-to-track cross bonds are within the entire measuring arrangement.



Key

1 insulating rail joint

Figure A.5 — Test of insulating rail joints

In on-status, a constant current of a few Ampere is fed into the rail across the rail joint to be tested. The functionality of the rail joint results from the current flowing towards the joint and away from the joint. For the measurements the voltage drop $U_{1,on}$ and $U_{2,on}$ along 10 m long rail sections is measured.

In off-status, directly after the switching off of the current the voltages $U_{1,off}$ and $U_{2,off}$ are registered.

The functionality of the insulating rail joint F_J is stated in percent:

$$F_J = \frac{U_{2,on} - U_{2,off}}{U_{1,on} - U_{1,off} + U_{2,on} - U_{2,off}} \times 100 \% \quad (\text{A.7})$$

where

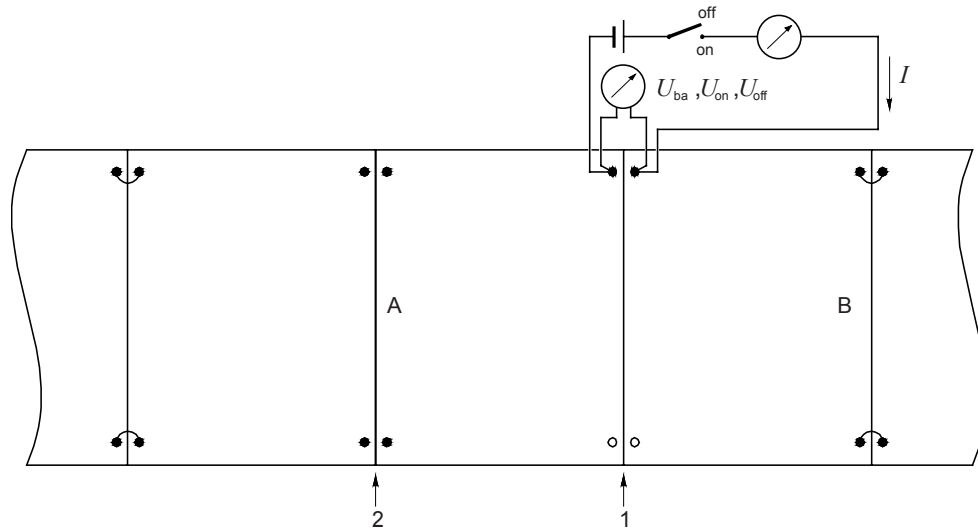
- F_J is the functionality of the insulating rail joint in percent;
- $U_{1,on/off}$ is the voltage drop in rail measuring section 1 in volts (V);
- $U_{2,on/off}$ is the voltage drop in rail measuring section 2 in volts (V).

Measured values of $F_J \leq 95 \%$ indicate that a galvanic connection across the joint exists or that the insulating rail joint is faulty.

A.6 Insulating joints between metal reinforced structures

Figure A.6 shows the measuring arrangement for the testing of the insulating joint between structure A and B. A second insulating measurement joint is needed to be opened during the time of measurement, and closed during operation.

NOTE Without opening joint 2 the resistance of the insulating joint 1 corresponds to the sum of the earth resistances of the structures A and B as a first approximation taking into consideration the mutual influence. Due to the big surfaces, which are in contact with the earth, this resistance is very small, which means that it cannot be used for assessment of the effectiveness of the insulating joint 1. When the adjacent insulating joint 2 is opened, a part of structure A is switched off so that its earth resistance is decisive for the measured resistance of the insulating joint 1.



Key

- 1 insulating joint to be measured
- 2 joint to be opened to perform measurement
- A structure A
- B structure B

Figure A.6 — Test of insulating joints in metal reinforced structures

The resistance test is made with the four-pole measurement method. Before current is fed in for the first time an initial basic voltage U_{ba} is measured at the insulating joint. Thereafter, a current of approximately 10 A is fed in for a few minutes. Before the current is switched off the current I and the voltage U_{on} are measured at the insulating joint. The voltage U_{off} is measured approximately 1 s after interruption of the current.

The joint resistance R_{joint} is calculated according to Equation (A.8):

$$R_{joint} = \frac{U_{on} - U_{off}}{I} \quad (A.8)$$

where

- R_{joint} is the resistance of the joint in ohms (Ω);
- U_{on} is the voltage during on-status in volts (V);
- U_{off} is the voltage during off-status after interruption of the current in volts (V);
- I is the injected current in amperes (A).

If $R_{joint} \geq 0,5 \Omega$ and the polarisation voltage $U_{off} - U_{ba} \geq 0,1 \text{ V}$ the resistance of the joint is high enough.

Annex B
(informative)

**Stray current assessment –
Rail insulation assessment using rail potential**

B.1 Continuous monitoring of the rail potential

For the continuous monitoring, the rail potential is registered at dedicated locations along the line, like in substations or passenger stations. In order to become independent from the varying traffic along the day, an averaging process is used. For the averaging time 24 h are recommended. This method works continuously and does not affect the train traffic.

If there is a change in the average rail potential, a change in the rail to earth conductance can have occurred, which gives a reason of concern for increased stray currents. Therefore the average value is compared with the value of the reference situation where the system meets the requirements according to this European Standard.

NOTE In existing systems with unclear stray current situation the reference situation is difficult to obtain. The distance between the measuring points depends upon the desired resolution for locating of the position of such changes. The shape of the rail potential along the line is characterized by the substation locations, time table and the train characteristics in traction and braking mode. It is practical to place the registration points e.g. in substations and passenger stations in order to be able to register a typical rail potential shape along the line. By this method it is possible to find out and to indicate the position of deficiencies in the electrical separation of the return circuit from installations with contact to earth, e.g. tunnels, bridges or other civil structures beneath or beside the track bed.

Using a centralized data acquisition system, an automatic indication of the situation and location of a rail to earth connection can be provided for maintenance purposes, see Figure B.1.

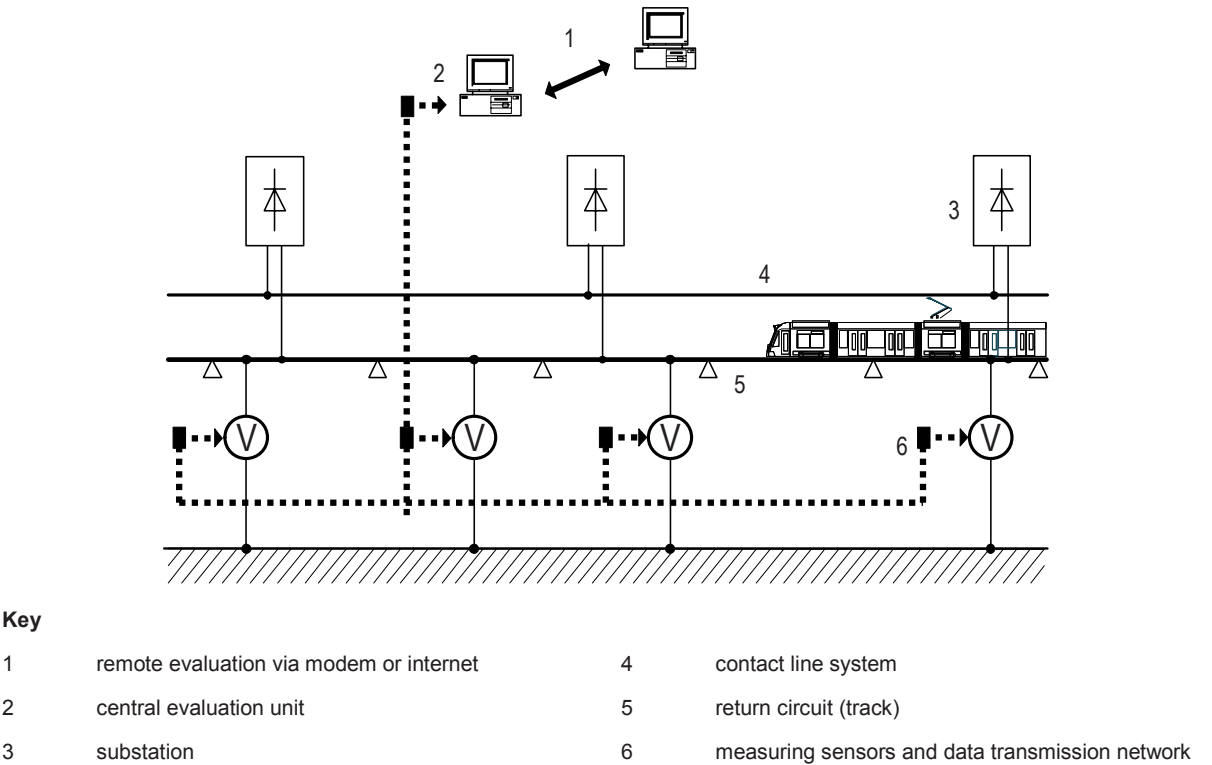


Figure B.1 — Continuous monitoring of the rail potential

B.2 Repetitive measurements of the rail potential to monitor the conductance

The preconditions for the measurements should be the same as during the previous reference measurements. Along the railway line several measuring points are determined. These can be close to substations, passenger stations, technical buildings or buildings and installations where stray currents can cause specific problems.

At these points existing or additionally installed earth electrodes can be used as the earth reference points. The measuring arrangement corresponds to Figure B.1 without centralised evaluation. At the measuring points the rail potential is measured and recorded by means of a data logger or voltmeter provided with minimum, maximum and mean storage functions. It is helpful to plot the three (min., max., mean) values versus the route graphically for better assessment. The time period for the measurement should be sufficiently long to obtain a useful average value.

From each location the arithmetic mean values are determined and the maximum and minimum values are noted. These values form a voltage characteristic along the line. This characteristic depends on the parameters like conductance per unit length, rail resistance and traffic. The voltage characteristic along the line indicates changes in the rail insulation. In case of recognised changes, more comprehensive investigations using more detailed measurements are required. Countermeasures can be necessary depending on the results.

NOTE 1 The period could be the hour of the highest traffic or alternatively approximately three times the time table cycle.

NOTE 2 Care should be taken in interpretation of the results, when the preconditions have been changed, like traffic or line configuration.

Annex C (informative)

Estimation of stray current and impact on metal structures

C.1 Estimation of the stray currents passing from the running rails to the earth

The traction return current flowing in the running rails causes changes in the rail potential leading to stray current flow into the earth via the track insulation.

Considering the risk of corrosion, the stray current per length is decisive for the loss of material.

The most severe case is a dead-end line or line extension, which is connected with an existing rail network.

For the calculation method the following assumptions are used:

- the existing railway is modelled as a *Norton* equivalent circuit. The source admittance is estimated by way of the inverse value of the characteristic resistance of the system;
- the traction current is fed in the return circuit at the end of this section.

The change in rail potential is calculated as follows:

$$U_{RE} = 0,5 \times I \times R_C \times \left(1 - e^{-\left(\frac{L}{L_C}\right)} \right) \quad (C.1)$$

$$R_C = \sqrt{\frac{R'_R}{G'_{RE}}} \quad (C.2)$$

$$L_C = \frac{1}{\sqrt{R'_R \times G'_{RE}}} \quad (C.3)$$

where

- U_{RE} is the rail potential;
- I is the average value of the traction return current in the considered section in the hour of the highest load;
- R_C is the characteristic resistance of the system running rails/structure;
- L_C is the characteristic length of the system running rails/structure;
- L is the length of the considered line section;
- R'_R is the longitudinal resistance of the running rails including parallel return conductors per length;
- G'_{RE} is the conductance of the running rails versus earth per length.

Using the rail potential and the conductance of the running rails versus earth the stray current per length is calculated according to Equation (C.4):

$$I'_S = U_{RE} \times G'_{RE} \quad (C.4)$$

where

- I'_S is the stray current leaking from the rails relative to the length.

Equations (C.1) and (C.4) result in Equation (C.5):

$$I'_S = 0,5 \times \frac{I}{L_C} \times \left(1 - e^{-\left(\frac{L}{L_C}\right)} \right) \quad (C.5)$$

If the stray current per length, divided by the number of parallel tracks is less than 2,5 mA/m, the conditions according to 5.2 are fulfilled.

NOTE The results of Equation (C.5) are conservative because a dead-end track is considered and because the train movements in the adjacent line sections are not considered. Therefore, the calculated values might be higher than in reality. If the result of the calculation exceeds 2,5 mA/m per single track, a more detailed calculation should be used.

C.2 Estimation of the longitudinal voltage in metal reinforced structures

In case of structures of reinforced concrete, e.g. tunnels, viaducts and reinforced track beds, the stray current leaks from the running rails into the reinforcement. If the reinforcement is not longitudinally interconnected, the stray currents flow into the earth via the outer reinforcement of the structure. In areas where the conductance is not homogeneous, concentrated leakage of stray current can arise and lead to corrosion on the outer reinforcement. A low-resistive interconnection of the reinforcement in the longitudinal direction reduces the longitudinal voltage drop along the reinforcement. If this voltage is less than the values given in EN 50162:2004, Table 1, there is no major concern of stray current corrosion. Therefore, the longitudinal voltage U_S is to be calculated for metal reinforced structures in addition to the stray current.

The longitudinal voltage drop in metal reinforced structures, caused by train operation, depends on the following affecting parameters:

- length of the considered line section;
- length of the adjacent line sections;
- conductance between the running rails and the structure;
- conductance between the structure and the earth;
- longitudinal resistance of the running rails;
- longitudinal resistance of the interconnected structure;
- traction return current in the considered line section;
- traction return currents of adjacent lines.

For a return circuit section in an infinitely long metal reinforced structure the longitudinal voltage is calculated as follows:

$$U_S = 0,5 \times I \times L \times \frac{R'_R \times R'_S}{R'_R + R'_S} \times \left(1 - \frac{L_C}{L} \times \left(1 - e^{-\left(\frac{L}{L_C}\right)} \right) \right) \quad (C.6)$$

$$L_C = \frac{1}{\sqrt{(R'_R + R'_S) \times G'_{RE}}} \quad (C.7)$$

where

- U_S is the longitudinal voltage in the metal reinforced structure;
- G'_{RE} is the conductance of the running rails versus earth per length;
- I is the average value of the traction return current in the considered section in the hour of the highest load;

- L is the length of the considered line section;
- L_C is the characteristic length of the system running rails/structure;
- R'_R is the longitudinal resistance of the running rails including parallel return conductors per length;
- R'_S is the resistance of the structure per length.

NOTE The results of Equation (C.6) are conservative. It is assumed that the structure on each side of the considered section is infinitely long. Furthermore, it does not consider train movements in the adjacent sections and the conductance per length between structure and earth. The calculated values might be higher than in reality. If the result of the calculation exceeds the values given in EN 50162:2004, Table 1, a more detailed calculation method should be used.

Annex ZZ (informative)

Coverage of Essential Requirements of EC Directives

This European Standard has been prepared under a mandate given to CENELEC by the European Commission and the European Free Trade Association and within its scope the standard covers all relevant essential requirements as given in Annex III of the EC Directive 96/48/EC (HSR), in Annex III of the EC Directive 2001/16/EC (CONRAIL) and in Annex III of the EC Directive 2008/57/EC (RAIL).

Compliance with this standard provides one means of conformity with the specified essential requirements of the Directives concerned.

WARNING: Other requirements and other EC Directives may be applicable to the products falling within the scope of this standard.

Bibliography

IEC 60050-811:1991, *International Electrotechnical Vocabulary – Chapter 811: Electric traction*

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