

BRITISH STANDARD

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Protection against corrosion by stray current from direct current systems

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ICS 29.020; 77.060

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National foreword

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Protection against corrosion by stray current from direct current systems

Protection contre la corrosion
due aux courants vagabonds
des systèmes à courant continu

Schutz gegen Korrosion
durch Streuströme aus
Gleichstromanlagen

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CENELEC

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Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

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Foreword

This European Standard has been prepared by CENELEC BTTF 114-1, Protection against corrosion by stray current from direct current systems.

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Introduction

Stray currents originating from direct current systems may cause severe material damage by corrosion, stray current corrosion, on buried or immersed metal structures (see Annex A). Particularly, long buried horizontal structures, e.g. pipelines and metal sheathed cables, may be in danger of this type of corrosion. Since corrosion damage can appear after only a short time of exposure to stray current it is important to make provisions for protective measures at an early stage and also to check the effect of these measures regularly.

This standard describes appropriate measures that can be applied to interfering d.c. systems and, if necessary, to structures which are, or which can be, exposed to stray current corrosion. The standard also gives measurement criteria for determining when these measures must be applied. Measurement techniques used on d.c. interfered structures are described in EN 13509.

The measures described in this standard are aimed for protection against stray current corrosion. For effective protection against other types of corrosion other measures have to be applied.

1 Scope

This standard establishes the general principles to be adopted to minimize the effects of stray current corrosion caused by direct-current (d.c.) on buried or immersed metal structures.

The standard is intended to offer guidance for:

- the design of direct current systems which may produce stray currents;
- the design of metal structures, which are to be buried or immersed and
- which may be subject to stray current corrosion;
- the selection of appropriate protection measures.

The standard mainly deals with external stray current corrosion on buried or immersed structures.

However stray current corrosion may also occur internally in systems containing an electrolyte e.g. near insulating joints or high resistance pipe joints in a water pipeline.

These situations are not dealt with in detail in this standard but principles and measures described here are generally applicable for minimizing the interference effects.

Stray currents may also cause other effects such as overheating. These are not covered in this standard.

D.C. systems that can cause currents to flow in the earth or any other electrolyte, whether intentional or unintentional, include:

- d.c. traction systems;
- trolley bus systems;
- d.c. power systems;
- d.c. equipment at industrial sites;
- d.c. communication systems;
- cathodic protection systems;
- high voltage d.c. (HVDC) transmission systems;
- d.c. track circuit signalling systems. For stray currents from traction systems EN 50122-2 gives requirements for minimizing their production and for the effects within the railroad.

Systems which may be affected by stray currents include buried or immersed metal structures such as:

- a) pipelines;
- b) metal sheathed cables;
- c) tanks and vessels;
- d) earthing systems;
- e) steel reinforcement in concrete;
- f) steel piling.

An affected structure carrying stray currents, e.g. a pipeline or cable may itself affect other nearby structures (see Clause 8).

This standard does not address the effect of a.c. stray current. Where a.c. stray current is suspected, care should be taken when taking measurements on any components due to risk of large induced voltages. If a.c. stray current interference is present the criteria described in this standard will not apply.

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 50122-2:1998, *Railway applications - Fixed installations - Part 2: Protective provisions against the effects of stray currents caused by d.c. traction systems*

EN 12954:2001, *Cathodic protection of buried or immersed metallic structures – General principles and application for pipelines*

EN 13509:2003, *Cathodic protection measurement techniques*

3 Definitions

For the purposes of this European Standard, the terms and definitions given in EN 12954, EN 50122-2 and the following apply.

3.1

coating

electrically insulating covering bonded to a metal surface for protection against corrosion by preventing contact between the electrolyte and the metal surface

3.2

drainage (electrical drainage)

transfer of stray current from an affected structure to the current source by means of a deliberate bond

NOTE For drainage devices see direct drainage bond, unidirectional drainage bond and forced drainage bond

3.3

direct drainage bond

device that provides electrical drainage by means of a direct bond between an affected structure and the stray current source. The bond may include a series resistor to limit current

3.4

forced drainage bond

device that provides electrical drainage by means of a bond between an affected structure and the stray current source. The bond includes a separate source of d.c. power to augment the transfer of current

3.5

unidirectional drainage bond

device that provides electrical drainage by means of a unidirectional bond between the affected structure and the stray current source. The bond includes a device such as a diode to ensure that current can only flow in one direction

4 Information exchange and co-operation

During the design stage of buried or immersed metallic structures the possibility of both causing and suffering from stray current interference shall be taken into consideration in order to meet the criteria mentioned in Clause 6.

Electrical interference problems on buried or immersed metallic structures shall be considered with the following points in mind:

- the owner of the metallic structure may protect a structure against corrosion with the method that he considers to be the most suitable. However, electrical interference to neighbouring structures shall be maintained within the defined limits;
- stray currents, especially from d.c. traction systems are directly related to the design of the return circuits. This means that it is possible to limit the stray current but not to remove it entirely;
- where other structures that may be affected are present, the requirement to maintain interference within the defined limits applies to all affected structures.

This goal is best achieved by agreement, co-operation and information exchange between the parties involved. Information exchange and co-operation are important and shall be carried out both at the design stage and during operation of the systems. In this way possible effects, suitable precautions and remedies can be assessed.

The following information shall be exchanged:

- 1) details of new buried metallic structures;
- 2) cathodic protection installations or significant modifications;
- 3) d.c. traction system installations or significant modifications;
- 4) HVDC transmission line installation or modification.

Agreement and co-operation may be more effectively achieved and maintained by periodic meetings between interested parties, committees or other associations who can establish information exchange procedures and protocols.

5 Identification and measurement of stray current interference

5.1 Identification

In cases where there is a possible corrosion risk due to d.c. interference analysis of the situation shall consider electrical properties and the location of the possible source of interference as well as anomalies recorded during routine cathodic protection measurements.

There are four principal ways to identify stray-current interference. These are to measure one or more of the following:

- structure to electrolyte potential fluctuations;
- deviations from normal structure to electrolyte potentials;
- voltage gradients in the electrolyte;
- line currents in pipelines coupons or metallic cable sheaths.

NOTE The measurement of current fluctuations and current polarity changes is particularly useful for identifying interference in complex networks.

After stray current interference has been identified further measurements must be carried out to assess the risk of corrosion.

5.2 Measurement

5.2.1 General

In order to assess the risk of corrosion to which any metal structure is exposed as a result of stray current, the positive potential shift of the affected structure shall be considered (see 6.1). If cathodic corrosion (see Annex A and EN 12954) of the metallic structure is likely to occur corrosion risks shall also be assessed by reference to the negative shift of the potential of the structure (see 6.2). The structure to soil potential should be measured with respect to a reference electrode, which is placed directly above the interfered structure.

In order to identify stray current polarity and/or magnitude potential gradient measurements using two reference electrodes may be carried out. One of the two electrodes shall be placed immediately above the structure exposed to the interference and the other one at a distance of, ideally, not less than 10 m.

Measuring the magnitude and direction of current flow and/or the potential shift at coupons or test probes will help to assess a possible corrosion risk.

Measurement techniques, sample periods and the number of readings shall be selected to provide representative data. In order to ensure accurate measurements care should be taken to select suitable voltage recording equipment and due consideration given to input impedance, sample period (or chart speed) and signal conditioning and filtering.

Measurement techniques are described in EN 13509.

5.2.2 Non fluctuating interference

In case of non fluctuating interference structure-to-electrolyte potentials or voltage gradients in the electrolyte shall be measured while the stray current source is in and out of operation. The measured values during these two conditions shall be compared with each other. If the stray current source cannot be temporarily switched off, the interference should be extrapolated from tests made under different stray current source operation conditions.

5.2.3 Fluctuating interference

Where the potentials or voltage drops measured fluctuate, e.g. as a result of interference from a d.c. traction system, measurements should be made using a continuous chart recorder or digital data logger. The recording shall include the period of time when maximum interference is expected as well as a period of no interference if possible. Many sources of interference exhibit the maximum and minimum levels over a 24 h period.

It is advisable to record the measured values of the affected system and an operating parameter of the stray current source simultaneously to allow a clear association of the stray current to the source.

Values recorded during the non operational period of the interfering system shall be considered as the normal or unaffected potentials.

NOTE A judgment should be made where the interfering system is not de-energised during non operational periods.

6 Criteria for stray-current interference

6.1 Anodic interference

A positive shift in potential on the structure constitutes anodic interference (see Annex A).

6.1.1 Structures without cathodic protection

Anodic interference (see Annex B) on structures without cathodic protection is acceptable if the positive potential shift ΔU is lower than the criterion given in Table 1.

NOTE 1 The acceptable positive potential shift ΔU (ohmic voltage drop, i.e. IR-drop, included) is related to the electrolyte resistivity since the IR-drop part of the measured potential shift increases with increasing resistivity (see Annex C).

NOTE 2 It is difficult to assess whether anodic interference meets the acceptance criterion of Table 1 where the potentials are rapidly fluctuating. A judgement should be made regarding the duration and extent of the potential excursions beyond the criterion as to whether or not the excursions are acceptable. This judgement may be based on the duration and frequency of the excursions or upon the average potential shift. If the results of the judgement are inconclusive then IR free potential measurements should be made and the criterion of Table 1 column three should be applied ($\Delta U/\text{mV}$ excluding IR drop)

Table 1 – Acceptable positive potential shifts ΔU for buried or immersed metal structures which are not cathodically protected

Structure metal	Resistivity of the electrolyte ρ (Ωm)	Maximum positive potential shift ΔU (mV) (including IR-drop)	Maximum positive potential shift ΔU (mV) (excluding IR-drop)
Steel, cast iron	≥ 200	300	20
	15 to 200	$1,5 \times \rho^*$	20
	< 15	20	20
Lead		$1 \times \rho^*$	
Steel in buried concrete structures		200	
* ρ in Ωm			

6.1.2 Structures with cathodic protection

Structures protected against corrosion by cathodic protection shall be deemed to be exposed to unacceptable stray current interference if the IR free potential is outside the protective potential range (see EN 12954).

To evaluate the acceptability of stray current interference the installation of test probes and coupons should be considered.

In situations with fluctuating interference current probe measurements as described in Annex D can also be used to evaluate the acceptability of interference.

If in special situations (e.g. under d.c. traction influence) there are reasons to doubt the accuracy of the measurement method used other measurement techniques (e.g. weight loss coupons) can be used to establish that the structure is cathodically protected.

Measurements should be carried out during a period of normal operation of the interfering system.

6.2 Cathodic interference

Cathodic interference (see Annex B) by stray currents shall be deemed to be unacceptably high if the interference causes the IR free potential to be more negative than the limiting IR-free potential (see EN 12954).

Negative potential shifts due to cathodic interference on a certain part of a structure (usually) implies that there exist other parts which are subject to anodic interference (see 6.1). If very negative potential shifts (e.g. $\Delta U > 500$ mV, IR-drop included) are measured, it is recommended to identify areas with anodic potential shifts to confirm compliance with 6.1.

Values recorded during the non operational period of the interfering system shall be considered as the normal or unaffected potentials.

7 Reduction of stray current interference – Modifications to current source

7.1 General

Measures taken to minimise the effects of stray current interference should commence with the source of the interference. If these are impractical or ineffective, then attention should be turned to the interfered structure. In some cases it may be necessary to introduce interference mitigation measures at both, to achieve an acceptable interference level.

In some cases the source of interference originates from a structure that is itself interfered with. This is known as secondary interference. Where such cases of secondary interference exist it is advised to modify the original source of interference first. The source of secondary interference may have to be modified if it is not possible to modify the original source.

7.2 Principles

Under normal operating conditions the earth shall not be used to carry any direct currents. For exceptions to this principle see 7.5, 7.7, 7.8.

Structures which are a source of interference shall not be connected to foreign buried or immersed metal structures unless it is necessary for safety or stray current corrosion protection reasons.

7.3 Direct current systems at industrial sites

All conductors of direct current systems (such as direct current power systems and direct current welding equipment) shall be insulated from earth. When for some reasons, for instance by personnel safety, earthing or equipotential bonding is necessary, special care shall be taken in order to avoid stray currents, for instance earthing at only one point.

The weld current circuit shall be as short as possible. Earthed metal structures such as railroad or crane tracks, overhead pipe crossings or buried pipelines shall not be used to conduct current.

7.4 Direct current systems at ports

7.4.1 Cranes

New crane installations at ports should be designed for alternating current operation with any direct current required for crane operation generated locally at the point of use. Each conductor carrying direct current should be insulated from earth.

If a direct current crane system cannot be operated without an earth connection, as in the case of an existing installation, special measures shall be taken in order to avoid stray currents e.g. by installing an insulated return conductor. A stray current drainage system shall be provided if stray current interference to buried metal structures is unacceptably high.

7.4.2 Quayside direct current welding stations

Each ship shall be served by one or several independent quayside welding stations. A single direct current welding system serving several ships may be a source of stray currents between the ships causing severe dolphin or fender corrosion damage as stray current interference is not significantly reduced by equipotential bonds between ships.

Connections for the operation of welding equipment shall be directly bonded to the ships' hulls, e.g. by welding.

NOTE Such problems can be overcome by placing the welding station(s) on board.

7.4.3 Direct current power supply to ships

Direct-current power systems on ships featuring complete earth insulation and earth protective relays may be supplied with d.c. electric power from shore.

If a direct-current power system on a ship features single phase earthing, alternating current power shall be supplied to the ship and rectified on board for use in the direct-current power systems.

7.5 Direct current communication systems

All communication systems shall be designed such that no direct current normally flows through the earth. Direct-current pulses such as pulses for dialling or earthing may flow through the earth. Direct currents shall not be the source of any stray-current interference with nearby pipeline or cables. Pipelines or cables shall not be used for earthing connections.

Traffic signals shall be designed such that direct currents do not normally flow through the earth.

7.6 Direct current traction systems

The traction system should be designed to reduce the stray currents flowing into the ground in order to reduce or eliminate the effects on foreign structures. Direct current traction systems are generally operated with the negative pole connected to the rails. In rare cases the positive pole is connected to the rails. Modern d.c. operated railways use a current feedback system during braking. The methods to be carried out shall comply with requirements given in EN 50122-2. They mainly consist of

- adjustment of the power supply system,
- improvement of the return circuit,
- isolation of the return circuit from ground, grounded metallic structures (pipelines, cables, bridges and tunnels) and other rail systems.

It is necessary to consider the requirements and the methods for suppressing stray current from the earliest stages of a d.c. railway project, so that the suppression of stray current is taken into account when the positions and the sizes of the substations are decided.

7.7 High-voltage direct current transmission systems

7.7.1 General

There are two main configurations for high voltage direct current (HVDC) transmission systems, monopolar and bipolar. Bipolar HVDC systems should be given preference to avoid stray current interference. The earthing of HVDC systems should be designed in such a way as to avoid current flowing through the earth during normal operation and to minimize earth current during faulty or unbalanced load conditions.

The entire system design shall consider the possible high level of stray currents to which buried or immersed metal structures may be exposed even at a substantial distance from the terminal earths of converter stations.

7.7.2 Terminal earth electrodes

Terminal earth electrodes shall be designed for installation in low-resistivity soil or seawater to minimize the total earthing resistance and near-surface voltage gradients around the earth electrodes.

The location of terminal earth electrodes can significantly affect the stray current interference on buried or submerged structures and must be carefully considered.

Calculated near surface voltage gradients should be checked by current tests with a test electrode prior to final decision on the location of the permanent earth electrodes.

7.7.3 Interference measurements prior to commissioning

When the earth electrodes are installed and prior to commissioning the stray current exposure areas (areas where the potential gradients may cause interference to other structures) shall be identified by reference to further calculations and preferably by test at reduced current. Metallic structures in the stray current exposure areas shall be located and tested for stray current interference such that the degree of interference on final commissioning can be estimated.

7.7.4 Interference measurements after commissioning

After commissioning further measurements of buried or immersed metallic structures within the stray current exposure area shall be undertaken. On bipolar systems with earthing system, the test shall be carried out at monopolar operation with each electrode operating both as an anode and as a cathode.

7.7.5 Protective measures

If the interference is unacceptable (see Clause 6), protective measures shall be taken (see Clause 8). Protective measures are required, even if interference only occurs at fault or unbalanced conditions in a bipolar system.

Instead of protective measures the parties concerned may enter into an agreement on the limits for fault and unbalanced operation of a bipolar system, e.g. highest level of current and maximum length of operation.

7.8 Cathodic protection systems

7.8.1 General

Cathodic protection systems may cause cathodic interference on structures buried in the vicinity of impressed current anodes.

Structures buried in the vicinity of a cathodically protected structure may experience positive potential shifts resulting from the potential gradients around large coating defects on the protected structure.

Measures to reduce or eliminate interference (see Clause 6) are described in the following paragraphs.

7.8.2 Adjustment of transformer rectifier output

The current output of the rectifier installed on an interfering structure shall be adjusted to the minimum level providing cathodic protection. In particular cases, the possibility of distributing the total current by additional rectifiers and ground beds could be considered.

7.8.3 Increasing coating resistance

Structures with high quality coatings require less cathodic protection current and hence minimize stray current interference. Coating defects on a cathodically protected structure may need to be located and repaired if the level of interference to nearby structures needs to be reduced.

7.8.4 Groundbed location

The interference from impressed current anodes depends on the current output, distance to neighbouring structures, and the resistivity of the surrounding medium.

The interference can be reduced by ensuring that the neighbouring structures are not within the area of the anode field where the potential gradient causes the potential to shift outside the limits detailed in 6.1 and 6.2. This can be achieved by:

- increasing the distance from the anode to neighbouring structures (either horizontally or vertically). This is the most effective method;
- reducing the voltage gradient around the groundbed by enlarging the groundbed geometry or by reducing the current output (see 7.8.2);
- locating distributed anodes close to the structure to be protected.

7.8.5 Drainage (electrical drainage)

In the case of anodic interference a drainage bond between the structures may be considered to limit the positive potential shift to within the limits detailed in Clause 6. If necessary a resistor may be included to restrict the current flow (see also Clause 8).

7.9 Interference caused by electrical drainage (secondary interference)

7.9.1 General

Drainage between a d.c. source and a structure can result in large d.c. currents returning to the current source via the structure. In this way the structure itself can become a source of interference (see also Clause 8 and Annex E)

7.9.2 Adjustment of drainage current

The drainage current shall be minimized. The use of automatically controlled drainage may be considered.

7.9.3 Increasing coating resistance

The principles mentioned in 7.8.3 apply.

7.9.4 Bonding

The principles mentioned in 7.8.5 apply.

8 Reduction of stray current interference – Modifications to the interfered structure

8.1 General

Modification to the interfered structure may consist of one or more of the following:

- a) installing mitigation devices (see 8.3);
- b) bonding the interfering and interfered structure (see 8.3.2, 8.3.3, 8.3.4);
- c) modifying the electrical continuity of the interfered structure (see 8.3.7);
- d) increasing the distance from the interfering structure (see 7.8.4).

The choice of remedial measures that may be applied to the interfered structure is dictated by criteria relating to both the interfering and the interfered structure such as:

- the location of the interfering source, which can be important in finding a solution which is both technically and economically satisfactory;
- the electrical status of the interfered structure, e.g. the nature of its insulation, its electrical continuity and whether cathodic protection is applied;
- the characteristics of the environment between the interfered structure and the interfering structure (soil conductivity and presence of nearby metallic structures);
- the level of stray current effects. Currents can vary from a fraction of an ampere to tens of amperes.

8.2 Design prerequisites

8.2.1 Coatings

The application of coatings to the interfered structure reduces the overall level of stray currents in the structure due to an increase of the structure to soil resistance. That simplifies the design and operation of countermeasures that may be required (see 8.3).

8.2.2 Isolation from other structures

There should be no unintentional direct metal contact with stray current sources or other metal structures (e.g. casings) that may be affected by stray currents; e.g. reinforced concrete structures shall have no direct metal contact with stray current sources.

8.2.3 Distance to be maximized

Since the interference level decreases with distance, new structures should be located as far as possible from known stray current sources.

8.3 Installation of mitigation devices

8.3.1 General

The installation of mitigation devices aims to reduce or eliminate stray current flow from the interfered structure directly into the environment, in order to meet the criteria detailed in Clause 6 (see Annex E).

This can be achieved by

- returning the stray current via a metallic bond (known as drainage) from the interfered structure back to the d.c. current source (see 8.3.2, 8.3.3, 8.3.4),
- returning the stray current through the ground by the use of earthing electrodes from the interfered structure back to the d.c. current source (see 8.3.5),
- applying a direct current through the ground or water to the interfered system (see 8.3.6).

In all cases the devices shall be adjusted so that the minimum current is used to achieve the desired objective.

The application of these measures requires the co-operation and approval of the concerned parties (see Clause 4).

The installation of a drainage bond between a long buried structure (pipe-line or cable) and a more negative structure (e.g. the negative busbar in a substation) increases the magnitude and extent of the stray current with the associated increased risk of interference to other buried structures. Such an action may also increase the rate of corrosion of the interfering structure (e.g. running rails in d.c. traction systems). Therefore, following such a connection investigations should be carried out on the source, and nearby or crossing foreign structures. If necessary, further counter-measures should be carried out (see 8.3.7).

NOTE It should be noted that in some countries the National Electrical and/or Safety Regulations may preclude the use of some mitigation techniques. In all circumstances the National Regulations in force take precedence over stray current mitigation requirements.

8.3.2 Direct drainage bond

In a direct drainage bond the current may flow in both directions. Therefore, direct drainage bonds may be used only when the potential at the connecting point of the bond to the d.c. current source is always more negative than the potential of the interfered structure, i.e. the direction of current flowing in the bond will never reverse.

Since the rails and the interfered structure may temporarily reverse polarity, direct drainage bonds shall not be installed on d.c. traction systems.

Structure-to-electrolyte potential shifts and current flow can be limited by the inclusion of a resistor in the bond. A fuse may also be integrated as a protection against overload.

This method is not intended to provide cathodic protection to the interfered structure.

NOTE In the special case of a ship which is berthed for a lengthy period in a port where steel sheet piling or facilities such as dolphins or fenders are protected by cathodic protection, then bonding of the ship to the structure protected by cathodic protection or other protective measures should be taken to prevent stray-current corrosion of the hull.

It should be noted that this practice is no longer recommended by the International Marine Organisation (IMO) and special precautions are required for use in hazardous areas or where ships are loading / offloading flammable material. (For further guidance see "International Safety Guide for Oil Tankers and Terminals (ISGOTT)" 4th ed, pub Oil Companies International Marine Forum, 1998.).

8.3.3 Unidirectional drainage bond

In an unidirectional drainage bond (also known as polarized electrical bond) the drainage current can flow only in one direction. Therefore, the unidirectional drainage bonds may be used, where the potential of the interfered structure is not always more positive than the potential of the d.c. source, e.g. d.c. traction systems.

As in the case of direct drainage bonds, it may be necessary to integrate a resistor and a fuse into the bond to restrict the current flow. The drainage current can also be automatically controlled by reference to a permanently installed sensing electrode.

This method is not intended to provide cathodic protection to the interfered structure.

8.3.4 Forced drainage bond

Generally forced drainage bond (also known as forced electric drainage) is used when a direct or unidirectional drainage insufficiently drains all stray currents from the interfered structure, because the interfering structure does not have a sufficiently negative potential. The technique is used where the stray current originates from a d.c. traction system.

A forced drainage bond incorporates a transformer rectifier in the bond between the interfered structure and the source of interference.

When applied on pipelines and cables, a forced drainage bond can protect longer sections against stray current corrosion than when a unidirectional drainage bond is used.

For large and frequent voltage variations between the running rails and the interfered structure the drainage current and the potential of the structure will vary considerably. In such situations the potential of the interfered structure can be maintained more negative than a preset value by the use of an automatically controlled forced drainage bond. When using this technique the selection of a suitable site for the permanent sensing electrode must be made with care.

8.3.5 Earthing electrode system

An earthing electrode system provides a metallic low resistance connection to the electrolyte (soil), thus reducing current flow from the interfered structure directly into the ground. This method may be used when the interference level is low and when the interfered structure is electrically well insulated (e.g. on long pipelines or cables interfered by stray currents from a HVDC transmission system or a cathodic protection system).

Earthing electrode systems using galvanic anodes generally do not protect a structure exposed to stray currents from a d.c. traction system.

8.3.6 Impressed current system

An impressed current system may be used to mitigate stray current effects when the level of interference is low. The aim is to mitigate the effects of stray current and not necessarily to provide cathodic protection. Impressed current systems are considered principally when one or more of the following exist:

- the interfered structure is well coated;
- the distance between the d.c. current source and the interfered structure is too great for a drainage bond;
- electric drainage between the interfering and the interfered structure is not appropriate, for safety reasons or to limit interference on neighbouring foreign structures;
- the interfered structure has to be permanently cathodically protected for other reasons.

As in the case of forced electric drainage an automatically controlled transformer rectifier may be used.

8.3.7 Modifying the electrical continuity of the interfered structure

For stray current interference on long structures, e.g. steel pipelines or reinforced concrete structures, it may be possible to limit the area of the structure exposed to interference by electrically isolating sections of the structure and hence to reduce the potential difference between the structure and the electrolyte. Electrical isolation can be achieved by installing isolating joints (see EN 12954 for more information).

When isolating joints are used for this purpose precautions should be taken to ensure that no corrosion is caused at the isolating joint by current flow across the isolating joint via the ground. The criteria mentioned in Clause 6 shall be met.

For pipes carrying a conductive electrolyte precautions should be taken against possible internal corrosion on the pipe wall at the anodic side of the isolating joint (see EN 12954).

Due to their isolating seals interference on coated cast iron pipes has to be considered only in areas with steep potential gradients (e.g. exceeding 200 mV per individual pipe length). Such conditions may occur within a distance of 10 m around the rails of d.c. operated traction systems and in the vicinity of ground beds. If unacceptable interference is expected the pipe joints shall be short-circuited by cables and measures detailed in 8.3.2, 8.3.3, 8.3.4 shall be applied.

In the case of buried high voltage cables some safety considerations, and in some countries the National Electrical and/or Safety Regulations, may preclude the use of isolation joints or require some additional precautions.

9 Inspection and maintenance

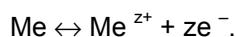
All plant and equipment which has been installed to limit the flow of stray current into the electrolyte, or to mitigate its effect, should be inspected and maintained at reasonable intervals (see EN 12954 for corrosion mitigation systems).

Annex A (informative)

Stray current corrosion, potential measurements and IR-drop

A freely corroding, i.e. not electrically influenced, metal structure which is surrounded by an electrolyte (e.g. soil, water or concrete) establishes an electrochemical potential (free corrosion potential or rest potential) versus the electrolyte. The potential can be measured versus a reference electrode, e.g. a saturated copper-copper-sulphate electrode (sat. Cu/CuSO₄) placed in the electrolyte. When electrically influenced by a foreign d.c.-current (stray current) the potential of the structure shifts in the positive (anodic) or in the negative (cathodic) direction where the current leaves or enters the metal surface.

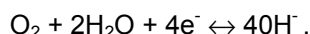
At the point where the stray d.c.-current *leaves* the metal structure an anodic corrosion reaction takes place at the metal/electrolyte interface, resulting in oxidation (dissolution) of the metal (Me),



This dissolution (mass loss) follows the Faraday electrolytic law, which for a bare iron or steel surface means that an anodic current (current leaving the surface) $I_{\text{d.c.}} = 1 \text{ A}$ dissolves 9,1 kg /year of iron. Expressed as corrosion (average penetration of the steel surface) the anodic current density $J_{\text{dc}} = 1 \text{ A/m}^2$ results in the corrosion rate 1,1 mm year of iron. This corrosion, caused by a current originating from an external d.c. current source, is known as stray current corrosion.

The anodic reaction results in a positive polarisation (positive potential shift) of the metal surface, and thus stray current corrosion can be identified by potential measurement. Due to the resistance in the electrolyte the stray current creates a voltage drop (IR-drop) in the surrounding electrolyte. Since the reference electrode usually is placed at some distance from the structure during the potential measurement, a part of the IR-drop is included in the measured potential value. This results in the recorded potential being more positive than the true potential at the metal/electrolyte interface.

At the point where the stray d.c. current *enters* the metal structure the cathodic part of the corrosion reaction takes place at the metal/electrolyte interface. This reaction can either be reduction of oxygen and production of hydroxide ions

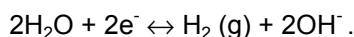


The cathodic reaction at the surface, where the current enters, lowers the corrosion rate which otherwise would be higher due to the corrosive influence of the surrounding environment.

NOTE This effect is put into practice under controlled conditions when cathodic protection is applied according EN 12954, resulting in corrosion rates $\leq 10 \mu\text{m/year}$.

The cathodic reaction results in a negative polarisation (negative potential shift) of the metal surface. Analogous to the case with an exiting stray current, an entering stray current creates an IR-drop in the surrounding electrolyte, but in this case with a reversed polarity of the IR-drop. A part of this IR-drop is included in the measured potential value, resulting in the recorded potential being more negative than the true potential at the metal/electrolyte interface.

However, at excessive cathodic current densities or in the absence of oxygen, decomposition of water takes place leading to evolution of hydrogen gas and production of hydroxide ions



The production of hydroxide increases the pH-value on the metal surface, which may result in cathodic corrosion of metals susceptible to high pH-values, e.g. aluminium and lead, and in the loss of bonding of organic protective coatings from the metal surface at coating defects (cathodic disbonding).

Prior to the evolution of hydrogen gas, atomic hydrogen is formed. If atomic hydrogen is dissolved in the steel it may, under certain circumstances, result in hydrogen embrittlement of high strength steels, especially steels with a martensitic structure. The production of hydroxide and the hydrogen evolution increase with increased cathodic current density.

Annex B (informative)

Principles of anodic and cathodic interference

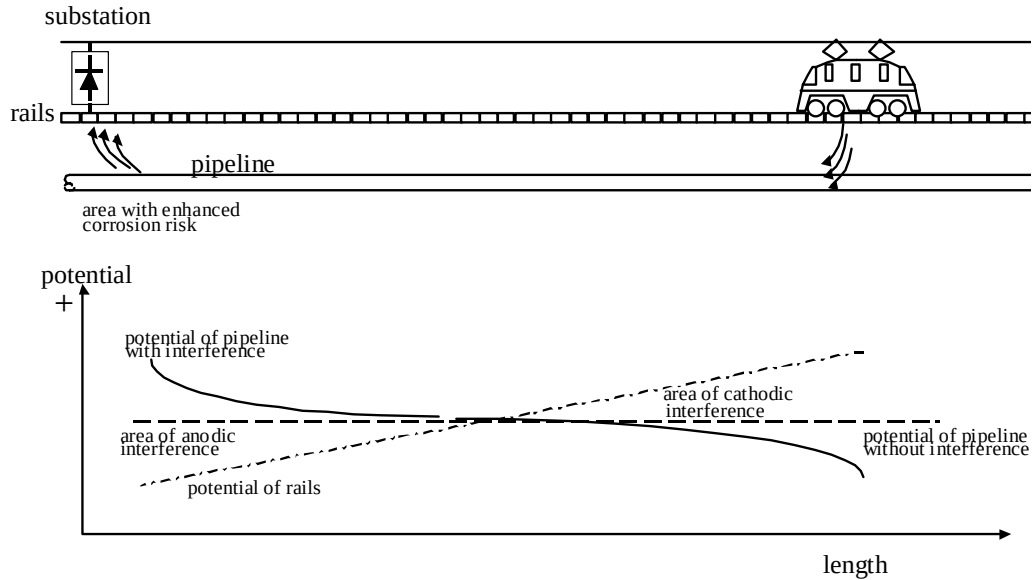


Figure B.1 - Principle of interference due to d.c. operated railways

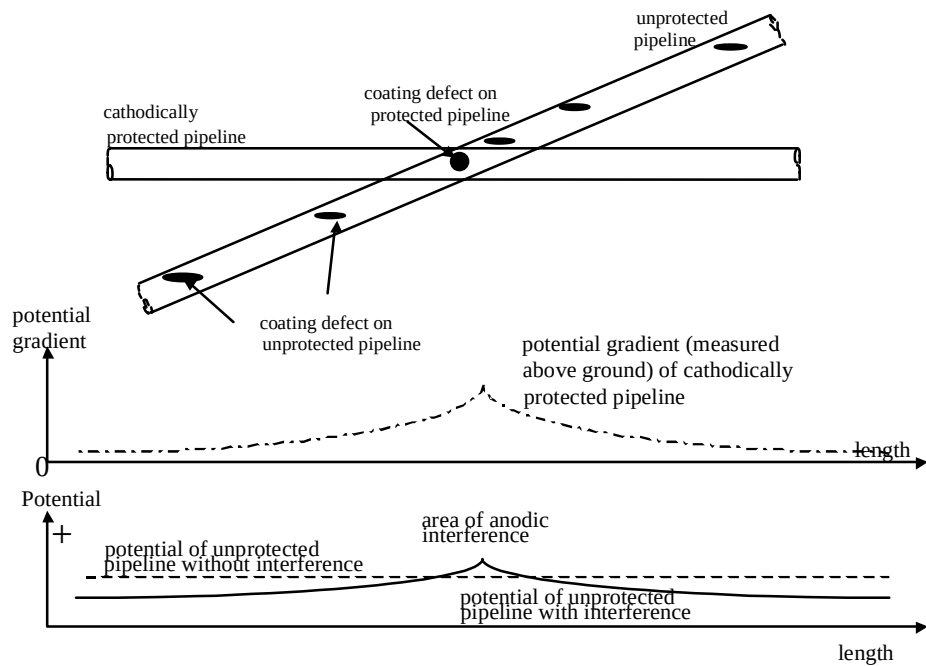


Figure B.2 - Principle of interference due to cathodic potential gradients (anodic interference)

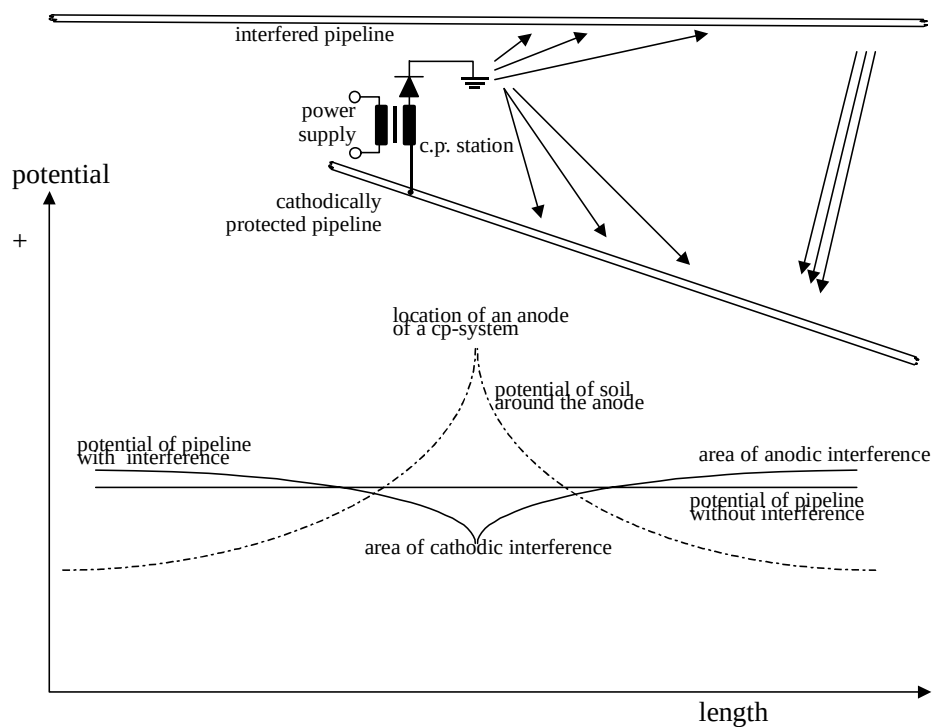


Figure B.3 - Principle of interference due to anodic potential gradients (cathodic interference)

Annex C (informative)

Criteria for maximum acceptable levels of potential shift ΔU of anodic interference

The potential shifts in Table 1 (see 6.1) have been derived from the following relationship:

$$\Delta U = c \cdot \rho ; (c = 1,5 \text{ mV}/\Omega\text{m for steel and cast iron; } c=1 \text{ mV}/\Omega\text{m for lead})$$

where ΔU is the acceptable potential shift in mV and ρ is the electrolytic resistivity in Ωm .

NOTE The formula has been established as a compromise based on different practises in several countries.

A measured potential shift smaller than 20 mV is always acceptable. A measured potential shift higher than 300 mV is not acceptable.

Although this relationship has been derived empirically there is a correlation to the current density, J , on exposed steel. Assuming a circular coating defect the current density, J , can be estimated:

$$J = \frac{8\Delta U}{\rho \pi d} ,$$

where ΔU is potential shift, ρ is the electrolyte resistivity, d is the exposed steel surface diameter. J remains constant if ΔU varies proportional compared to ρ .

Annex D (informative)

The use of current probes to evaluate fluctuating stray current interference on cathodically protected structures

Measuring method

Current probes can be used to evaluate fluctuating stray current interference on cathodically protected structures. A typical method to carry out the measurement with current probes is shown in Figure D.1:

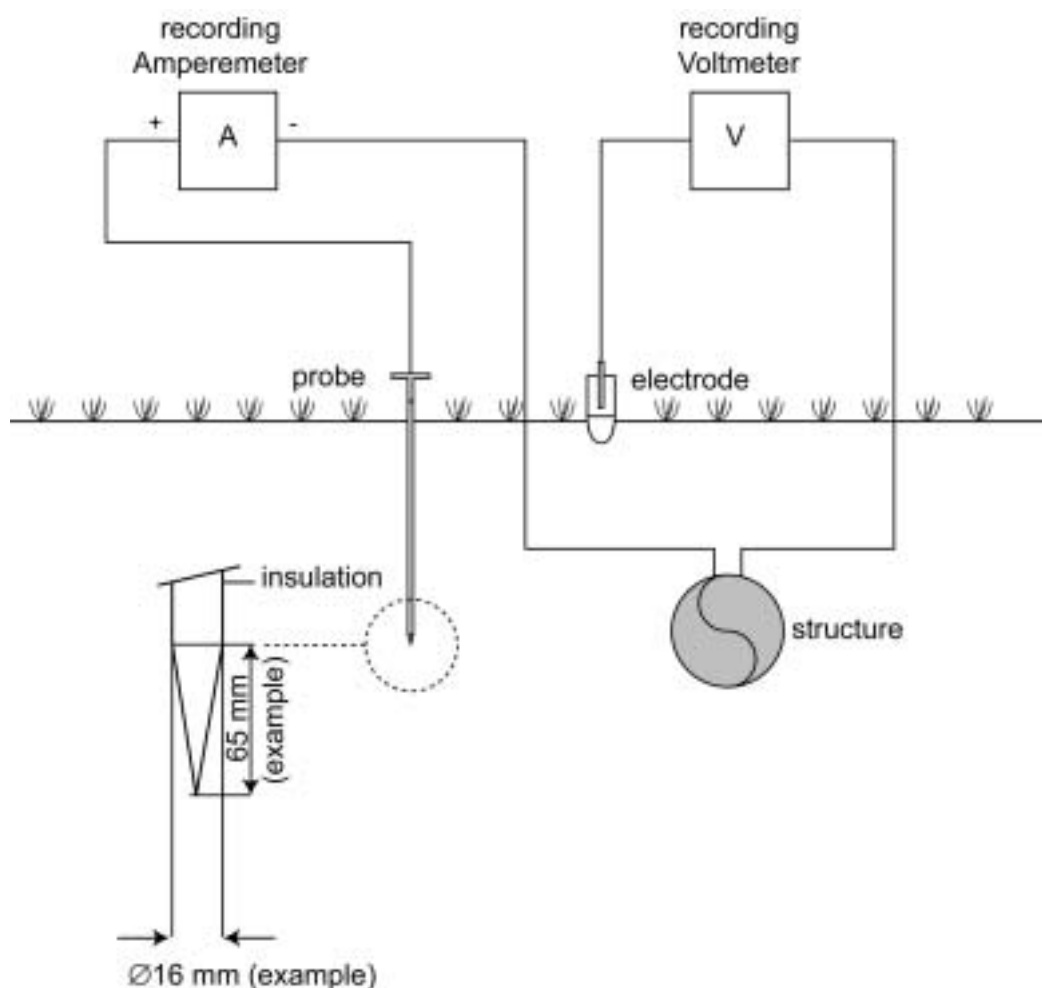


Figure D.1 - Measuring method

An insulated steel probe with a bare steel surface is pushed into the ground to the depth of the pipeline. The probe is electrically connected to the pipeline. The bare surface of the probe now functions as the steel surface in a simulated coating defect. The recording ammeter is used to determine the direction and the magnitude of the current. The measurement is typically carried out during a period of 24 h.

Procedure of measurement and evaluation

Step 1:

The probe current corresponding to the cathodic protection potential of the pipeline (according to EN 12954) is measured during a period when the pipeline is not interfered by fluctuating stray current (e.g. at night). This probe current is defined as 100 % (reference value) as shown in Figure D.2, period „A“).

Step 2:

The probe current (the resultant of cathodic protection current and stray current) is continuously recorded during a period of typically 24 h.

Step 3:

For evaluation the hour with the highest probe current reductions (i.e. the hour with the most positive potential fluctuations) is identified (period „B“ in Figure D.2).

Step 4:

Probe currents below any of the values given in column 1 of Table D.1 indicate a high risk of corrosion if their accumulated duration exceeds the corresponding values of column 3 of Table D.1.

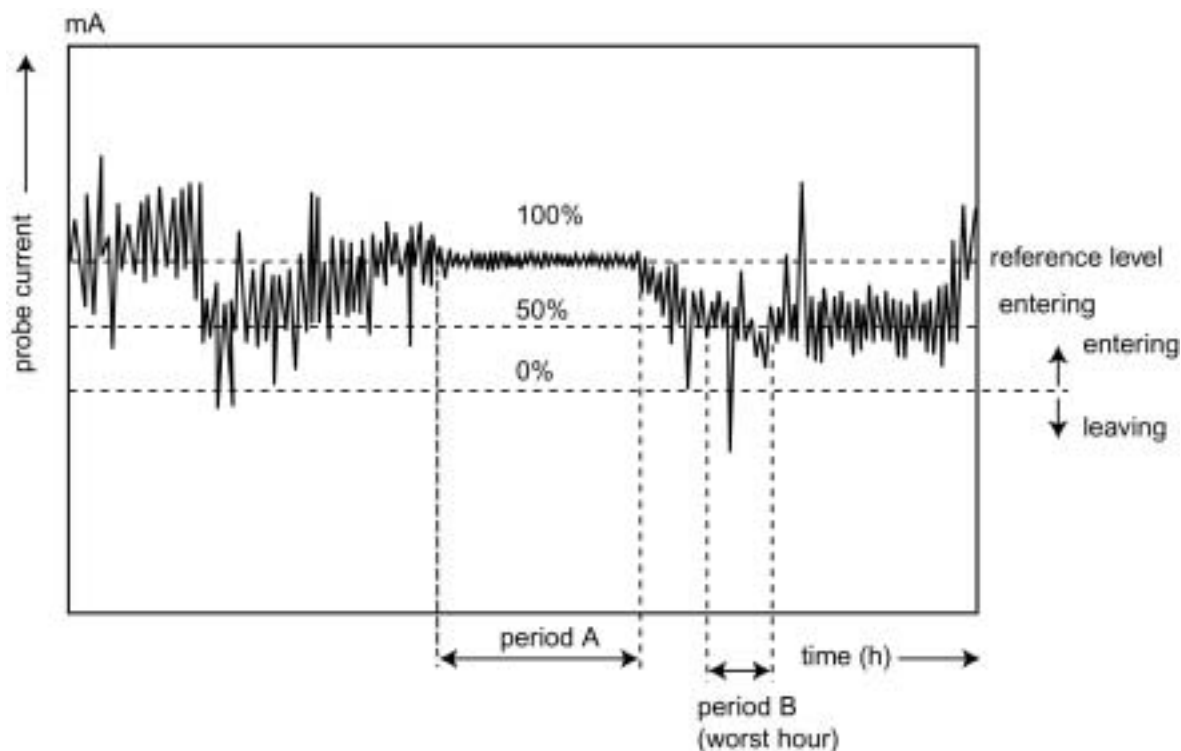


Figure D.2 - Example of the result of a probe current measurement („A“ indicates the period in which the reference level is measured; „B“ indicates the period with the highest reduction of the reference level).

Table D.1 – Current criteria in case of interference due to d.c. traction systems

probe current in % of the reference level	Maximum acceptable occurrence period	
	in % of the worst hour	in seconds
> 70	unlimited	
< 70	40	1 440
< 60	20	720
< 50	10	360
< 40	5	180
< 30	2	72
< 20	1	36
< 10	0.5	18
< 0	0.1	3.6

NOTE 1 The figures in Table D.1 are based on ten years practical experience

NOTE 2 Evaluation according to Table 1 may result in an overestimation of the corrosion risk in cases where the IR-free potentials (e.g. as measured in step 1) is considerably (e.g. 250 mV) more negative than the protection potential according to EN 12954).

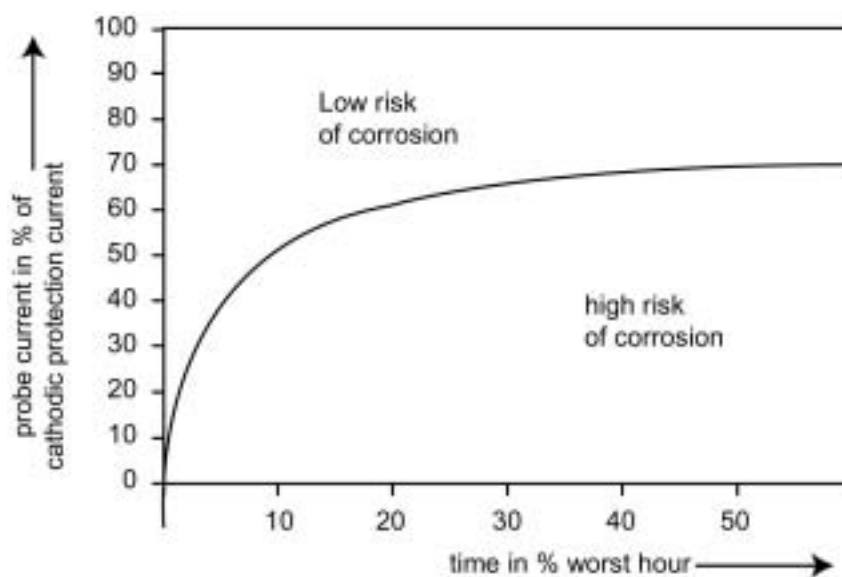


Figure D.3 - Graphical representation of Table D.1

Annex E (informative)

Interference situations and protection techniques

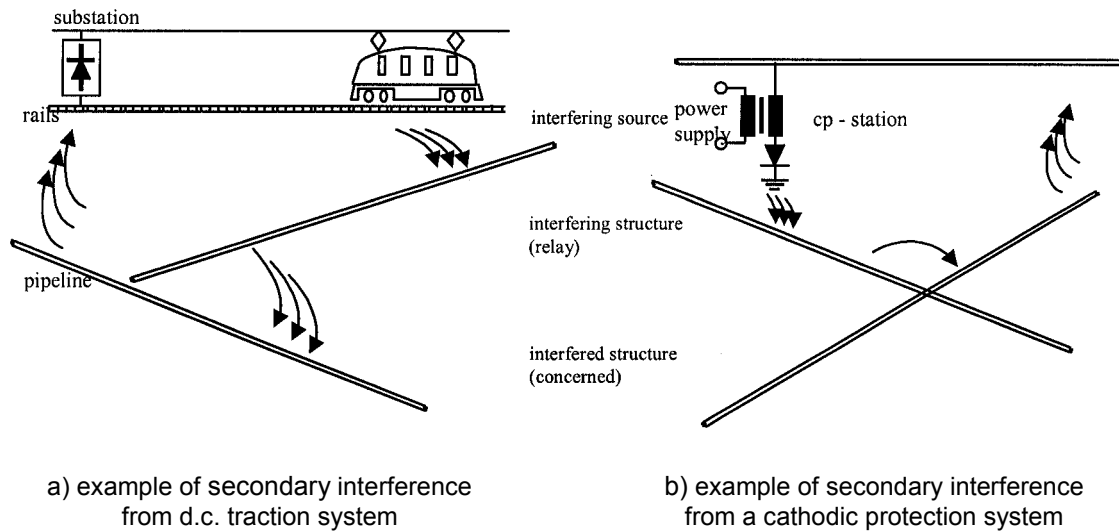


Figure E.1 - Examples for secondary interference

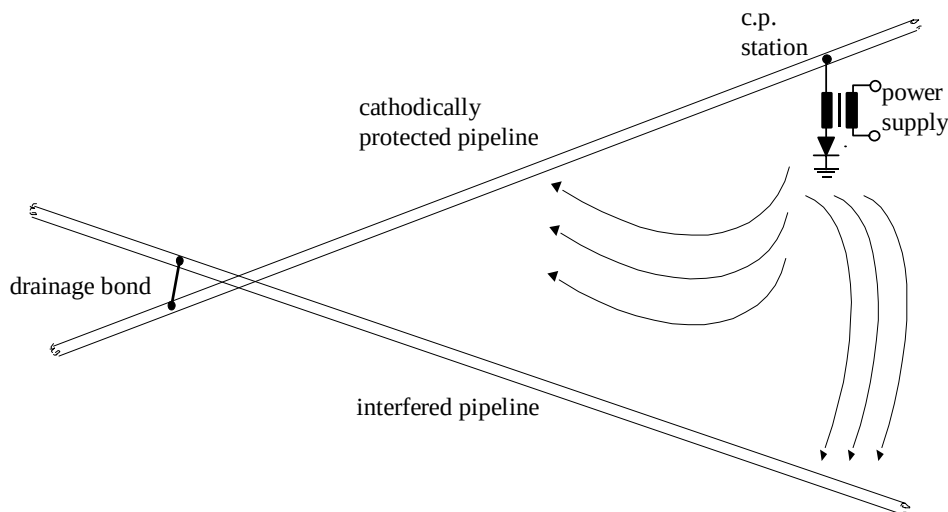


Figure E.2 - Mitigation of interference using a drainage bond

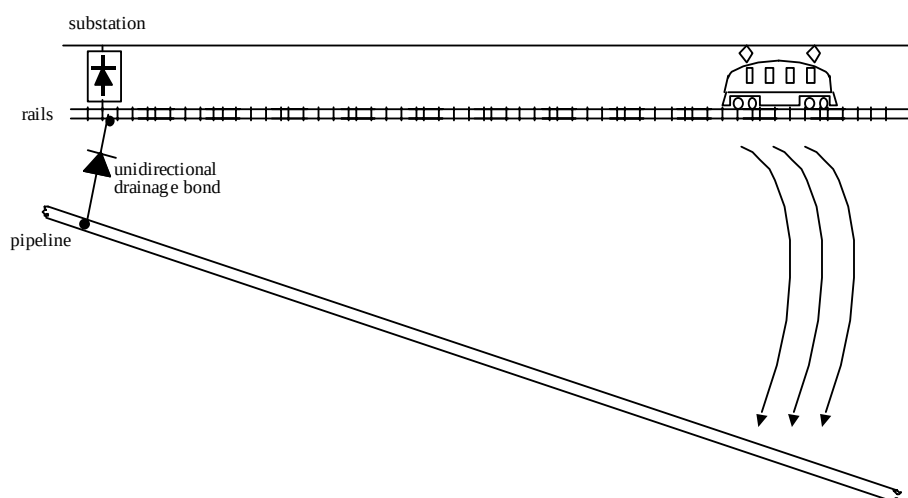


Figure E.3 - Mitigation of interference using a unidirectional drainage bond

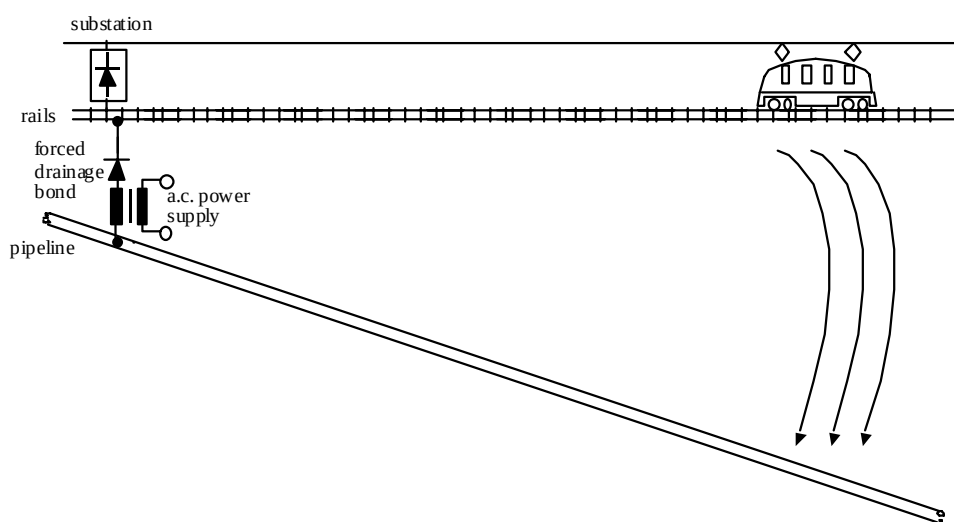


Figure E.4 - Mitigation of interference using a forced drainage bond

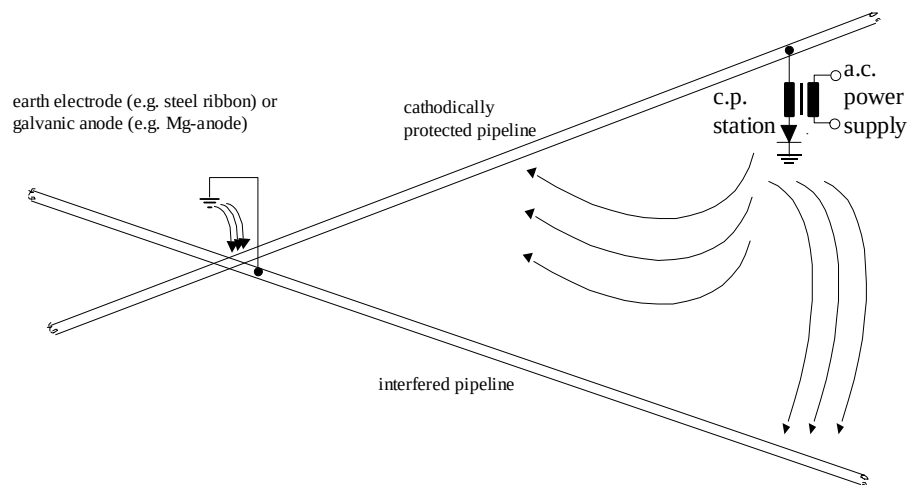


Figure E.5 - Mitigation of interference using an earthing electrode or a galvanic anode

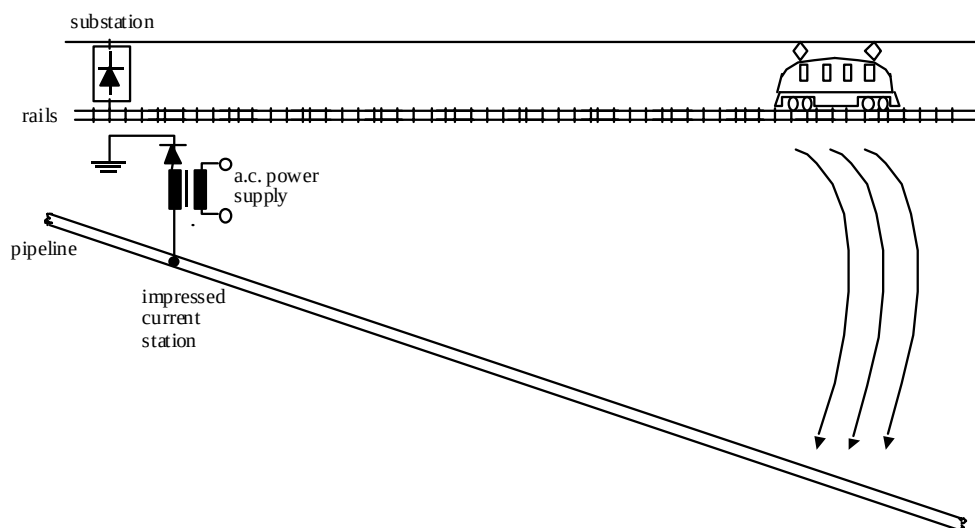


Figure E.6 - Mitigation of interference using an impressed current station

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