BS EN ISO 21857:2021

BSI Standards Publication

Petroleum, petrochemical and natural gas industries — Prevention of corrosion on pipeline systems influenced by stray currents

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The UK participation in its preparation was entrusted to Technical Committee PSE/17/2, Transmission pipelines.

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

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Industries du pétrole, de la pétrochimie et du gaz naturel - Prévention de la corrosion sur les systèmes de conduites soumis à l'influence de courants vagabonds (ISO 21857:2021)

Erdöl-, petrochemische und Erdgasindustrie - Vermeidung von durch Streuströme beeinflusster Korrosion an Rohrleitungssystemen (ISO 21857:2021)

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European foreword

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Foreword

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This document was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 2, *Pipeline transportation systems,* in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 219, *Cathodic protection,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

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Introduction

This document provides guidance for the prevention of external corrosion when a pipeline is influenced by electrical interference. Electrical interference can be from stray currents (defined in ISO 8044) and from naturally occurring interference caused by geomagnetic or tidal activity.

International Standards on cathodic protection (e.g. ISO 15589-1 and ISO 15589-2) refer to a structure-to- electrolyte potential value that is considered to indicate that cathodic protection is effective. When the potential is influenced by stray currents, however, it is not always possible to obtain a meaningful structure-to-electrolyte potential and other methods of assessment are needed. These other methods can include mathematical analysis of the potentials and/or direct assessment of the corrosion rate using electrical resistance probes.

An affected structure carrying stray currents, e.g. a pipeline or cable can itself affect other nearby structures.

This document is not intended to inhibit the use of alternative equipment or engineering solutions for individual applications. Where an alternative is offered, it is intended that any variations from this document be identified and documented.

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Petroleum, petrochemical and natural gas industries — Prevention of corrosion on pipeline systems influenced by stray currents

1 Scope

This document establishes the general principles for the evaluation and minimization of the effects of stray current corrosion on external surfaces of buried or immersed pipeline systems caused by AC and DC electrical interference.

Other stray current effects such as overheating, and interference with welding operations are not covered in this document.

A brief description of AC effects, general principles and some guidelines, are provided.

NOTE 1 See ISO 18086 for the effects of alternating current on buried or immersed pipelines.

Systems that can also be affected by stray currents include buried or immersed metal structures such as the following:

a) pipeline systems;

b) metal sheathed cables;

c) tanks and vessels;

d) earthing systems;

e) steel reinforcement in concrete;

f) sheet steel piling.

This document gives guidelines for

— the design of cathodic protection systems that might produce stray currents,

— the design of pipeline systems, or elements of pipeline systems, which are buried or immersed, and which can be subject to stray current corrosion, and

— the selection of appropriate protection or mitigation measures.

Internal corrosion risks from stray currents are not dealt with in detail in this document but principles and measures described here can be applicable for minimizing the interference effects.

NOTE 2 The impact of electromagnetic interference on above-ground appurtenances of pipeline systems is covered in EN 50443, IEC 61140, IEC 60364-4-41, IEC 60479-1, IEC 60364-5-52, IEC/TS 61201 and IEC/TR 60479-5.

This document can also be used for pipeline systems outside of the petrochemical and natural gas industries and other buried or immersed structures.

NOTE 3 EN 50162 provides guidance for railway related structures.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

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IEC 62128-2:2013, *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*

ISO 15589-1, *Petroleum, petrochemical and natural gas industries — Cathodic protection of pipeline systems — Part 1: On-land pipelines*

ISO 8044, *Corrosion of metals and alloys — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 15589-1, IEC 62128-2:2013, ISO 8044 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

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
remote earth
theoretical concept that refers to a ground electrode of zero impedance placed an infinite distance away from the ground under test

Note 1 to entry: In practice, remote earth is approached when the mutual resistance between the ground under test and the test electrode becomes negligible. Remote earth is normally considered to be at zero potential.

[SOURCE: IEEE Std 81-2012[1]]

3.3
conductive coupling
transfer of energy occurring when a part of the current belonging to the interfering system returns to the system earth via the interfered system

Note 1 to entry: Also, when the voltage to the reference earth of the ground in the vicinity of the influenced object rises because of a fault in the interfering system, and the results of which are conductive voltages and currents.

3.4
drainage
electrical drainage
transfer of stray current from an affected structure to the current source by means of a deliberate bond

Note 1 to entry: For drainage devices see *direct drainage bond* (3.5), *unidirectional drainage bond* (3.7) and *forced drainage bond* (3.6).

3.5
direct drainage bond
device that provides *electrical drainage* (3.4) by means of a bi-directional, metallic bond between an affected structure and the stray current source

Note 1 to entry: The bond can include a series resistor to reduce the current.

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3.6
forced drainage bond
device that provides *electrical drainage* (3.4) by means of a bond between an affected structure and the stray current source

Note 1 to entry: The bond includes a separate source of DC power to augment the transfer of current.

3.7
unidirectional drainage bond
device that provides *electrical drainage* (3.4) by means of a unidirectional bond between the affected structure and the stray current source

Note 1 to entry: The bond includes a device such as a diode to ensure that current can only flow in one direction.

3.8
telluric interference
voltages generated by geomagnetic field variations that cause variations in the observed pipe-to-soil potentials

3.9
electrical resistance probe
ER probe
device that measures metal loss by comparison of the calibrated resistance value of a piece of metal with known physical characteristics

3.10
sampling rate
measuring interval set by the operator

3.11
alternating current interference
AC interference
electrical disturbance generated by AC systems that affects buried or immersed pipelines by conduction and/or induction

Note 1 to entry: Powerlines, railway traction systems.

3.12
direct current interference
DC interference
disturbance, generated by DC systems, that affects buried or immersed metallic structures primarily by conduction

4 Abbreviations and symbols

4.1 Abbreviations

AC	Alternating current
ACVG	Alternating current voltage gradient
CP	Cathodic protection
DC	Direct current
DCVG	Direct current voltage gradient
emf	Electromotive force

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GIC	Geomagnetically induced currents
HVAC	High voltage alternating current
HVDC	High Voltage Direct Current
IR	Product of the current and resistance (I and R) that indicates the voltage drop error in a potential measurement
PV	Photovoltaic
r.m.s.	Root mean square

4.2 Symbols

a^{-1}	Per annum
B	Magnetic field
E	Structure/soil potential for non cathodically protected structures
E_a	Anodic potential
E_c	Cathodic potential
ΔE	Potential difference due to operation / non-operation of the interfering source
ΔE_a	Anodic potential shift (IR drop included)
$\Delta E_{a,avg}$	Average anodic potential shift
$\Delta E_{a,IR\ free}$	Anodic potential shift (IR drop excluded)
ΔE_c	Cathodic potential shift
ΔE_m	Measured interference
$\Delta E_{c,avg}$	Average cathodic potential shift
E_{cor}	Structure potential of a metal in a given corrosion system (ISO 8044)
$E_{IR\text{-}free}$	Structure potential without measurement error due to current flowing in the circuit
E_{on}	ON potential
$E_{on,avg}$	Average ON potential
E_p	Protection potential according to ISO 15589-1
E_{ref}	On potential required to achieve effective cathodic protection
F	Electric field
I_{cpn}	Coupon current
J	Current density
J_a	Anodic current density
J_c	Cathodic current density

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J_{cpn}	Coupon current density
J_{ref}	Reference value for current density (analogous to I_{ref})
ρ	Soil resistivity (Ω·m)
Q_a	Anodic charge during the period of anodic interference
Q_c	Cathodic charge during the period of cathodic interference
R_c	Coupon element resistance
R_{iso}	Isolation resistance, usually of a cable insulation
s	Seconds
$S \cdot km^{-1}$	Siemens per unit length
t	Time
T_a	Interval when the structure is anodic with respect to the selected value of E_{ref} or J_{ref}
$T_{a,max}$	Maximum duration of the anodic period
T_c	Interval when the structure is cathodic with respect to the selected value of E_{ref} or J_{ref}
v_{cor}	Corrosion rate
V_{CSE}	Voltage with respect to a copper/copper sulfate reference electrode

5 Information exchange and co-operation

Common sources of interference that can cause stray current corrosion are given in Clause 6. During the design stage of buried or immersed metallic pipeline systems, the possibility of both causing and suffering from stray current interference shall be taken into consideration and documented. The pipeline system should achieve the acceptance criteria identified in Clause 8. Construction work, major changes on existing structures, regenerative braking, etc. can require a detailed consideration of the interference situation.

Electrical interference problems on buried or immersed metallic pipeline systems shall be considered, and documented, with the following points in mind:

— The operator of the pipeline system can protect a structure against corrosion with the method that the operator considers to be the most suitable. However, levels of electrical interference on neighbouring structures shall be maintained within the defined limits given in Clause 8

— Stray currents, especially from DC traction systems, are directly related to the design of the traction return circuits. This means that it is possible to limit the stray current by traction circuit design, but not to eliminate it.

— Where other structures that might be affected are present, the requirement to maintain interference within the defined limits applies to all affected structures.

— Utility-scale photovoltaic (PV) installations can develop a steady state DC interference to adjacent buried pipelines. It is expected that the operator of the PV installation will maintain constant monitoring of the R_{ISO} value to verify the isolation resistance between the PV panels and the earth. The pipeline operator should be informed of any changes in the R_{ISO} values outside the threshold value.

— The operating characteristics of HVDC systems can change under fault and maintenance conditions. These changes can affect the corrosion risk to buried pipelines and such changes should be communicated in a timely manner to the pipeline operator.

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These goals are 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 is required to make a sound engineering judgement:

— details of buried metallic structures;

— cathodic protection installations or significant modifications to existing installations;

— DC traction system installations or significant modifications to existing installations;

— HVDC transmission line installation or modification to existing installations or modes of operation;

— details of any sources of DC installations that can cause interferences to buried pipelines;

— utility scale photovoltaic systems.

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

6 Common sources of interference that can affect corrosion

6.1 General

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

a) traction systems;

b) overhead lines for vehicles;

c) trolley bus systems;

d) power systems;

e) equipment at industrial sites, e.g. welding;

f) communication systems;

g) instrumentation systems;

h) cathodic protection systems;

i) high voltage transmission systems. See Annex E;

j) track circuit signalling systems. (For stray currents from traction systems, IEC 62128-2 gives requirements for minimizing their production and for the effects within the railway system);

k) photovoltaic power systems. See Annex H;

l) offshore wind farm power systems;

m) geomagnetic interference (telluric currents). See Annex D;

n) tidal fluctuations. See Annex G.

AC systems (see Annex F) that can induce voltages into buried structures include

— three phase power transmission overhead cables,

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— buried three phase power cables, and

— AC operated railways.

6.2 Direct current

6.2.1 General

Sources of DC that can affect the structure-to-electrolyte potentials on pipelines can either originate from industrial or natural sources.

6.2.2 Traction systems

There are various configurations of DC traction systems that are in common use. They generally differ in respect of the way that the current is returned to the substation(s). Whichever system configuration is used there will be some current that returns via the earth. IEC 62128-2 gives guidance on permissible limits.

6.2.3 Industrial systems

6.2.3.1 General

Industrial systems that use, or generate, DC should be provided with earthing systems that neither rely on long earth return paths nor deliberately utilize third-party structures for earthing purposes.

6.2.3.2 Welding

Welding return circuits should be configured to ensure that the return paths are as short as possible and do not exacerbate the risk of currents returning via third-party structures.

6.2.3.3 Photovoltaic interference on buried pipelines

Leakage currents in photovoltaic systems originate from a fault or from the systematic and inevitable flow of DC where there is cable insulation damage to PV modules and other array components. Under certain conditions, the DC leakage currents, if left unattended, or not detected at all, can cause accelerated stray current corrosion on metallic underground infrastructure, such as pipelines, buried near large, utility-scale PV systems.

6.3 Alternating current

6.3.1 General

AC powered systems can cause interference on pipelines due to inductive, conductive and capacitive coupling mechanisms, which are described in References [3] and [6].

It is possible that the voltage resulting from interference on the pipe can exceed acceptable levels of touch-potential and/or current densities that will lead to corrosion damage of exposed steel surfaces.

The potentials and current densities that are used to determine the risk of corrosion from AC interference are detailed in References [3] and [6].

Annex F provides additional information and one method to calculate the induced voltage in a section of pipe.

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6.3.2 Overhead and buried power lines

6.3.2.1 General

Overhead power lines can generate unacceptable voltages onto buried pipelines, primarily by induction. The induction is a result of magnetic coupling. The magnitude of the induced voltage depends on the distance, length of parallelism, inducing current magnitude, frequency and phase relationship.

6.3.2.2 Buried power cables

Buried power lines can generate unacceptable voltages onto buried pipelines, primarily by induction, in the same way as overhead power lines. It is preferable if buried cables are laid with the phase cables close to each other and formed in a trefoil configuration. Trefoil formation refers to a method of arranging the individual phase cables to reduce the net inductance because the phases are in anti-phase and cancel each other.

6.3.2.3 Railway systems

AC railway systems can be a source of interference. Where the pipeline is parallel to the railway, the coupling is primarily inductive. The rails of AC powered railways are earthed, and this can also result in conductive coupling to adjacent buried structures. AC railways can operate at 60 Hz, 50 Hz and 16,67 Hz. When evaluating the risks resulting from the effects of electromagnetic interference on buried pipelines running near AC electrified traction systems, the harmonic distortion in railway systems should be considered. The presence of harmonics can exacerbate voltages induced on buried pipelines[5].

6.4 High-voltage direct current transmission systems

There are two main configurations for high voltage direct current transmission systems, monopolar and bipolar. Bipolar HVDC systems should be given preference to avoid stray current interference. The earthing of HVDC systems shall 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 can be exposed, even at a substantial distance from the electrode station.

Buried HVAC and HVDC cables are joined together in joint bays installed along the cable route. The separation distance between joint bays is dependent on the cable operating voltage, conductor size and construction. Not all joint bays will have an earth local to the joint bay, but the cable screens will be bonded in each joint bay. The location of all earths should be advised by the cable system operator. Where an operator decides to install an earth at a joint bay the earth should be installed at a distance from buried pipelines that will ensure that the touch voltage created on a pipeline during fault conditions is within safe limits. AC and DC leakage currents through earth systems can also result in interference on buried utilities and should be minimized.

Additional information is given in Annex E.

6.5 Natural interference

6.5.1 General

Natural low frequency interference is caused by geomagnetic field variations and by tidal water movements.

6.5.2 Geomagnetic (telluric) interference

Geomagnetic field variations are variations in the earth's magnetic field. The geomagnetic field variations induce electric currents in the Earth and in long conductors such as pipelines and power

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transmission lines. These induced currents are generally referred to as telluric currents when related to pipelines and as GIC by the electric power industry. Both terms are used in literature and to be consistent with present pipeline practice this document will use the term telluric currents. (See Annex D for additional information).

6.5.3 Tidal interference effects

The movement of conductive seawater through the Earth's magnetic field acts like a dynamo and generates an electric field in the seawater. This drives an electric current (a flow of charge) in the seawater, perpendicular to the direction of water movement. Where this electric current meets the land, there is a build-up of electrical charge that creates a potential gradient both along the seafloor and inland perpendicular to the coast. (See Annex G for additional information).

7 Identification and measurement of stray current interference

7.1 Principle

The identification of the stray current interference is achieved by analysis of the measurements. The evaluation of the interference is performed by a comparison of the data with the acceptance criteria.

The measurements shall be planned to consider any known information relating to the interference acceptance criteria (Table 1 for DC). In particular, the following points should be considered:

— type of coupling of the interference (AC and/or DC);

— relative position to the stray current source (remote or nearby);

— anticipated duration of the anodic excursion ($T_{a,max}$);

— anticipated time dependence of the amplitude of $E_a - E_c$ as well as $J_a - J_c$ (Interference amplitude is constant or seasonally changing at constant T_a).

The measurement requires determination of the following:

a) the correct position for the reference electrode and/or coupons to be measured (See Annex B);

b) identifying the area of highest interference (Annex B);

c) Configuration of the coupon or probe (size and shape);

d) Connection of coupon or probe to the pipeline;

e) Sampling rate of the measuring system;

f) Duration of the measurements (see 7.3.6);

g) Switching ON/OFF ratio;

The evaluation of interference can be based on several different measurements at representative locations with respect to a reference electrode:

— structure potentials;

— current flowing through a coupon or probe;

— IR-free potential measurement of a coupon or probe;

— voltage between two reference electrodes;

— corrosion rate determined on a coupon or probe;

— line current measurement.

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A description of the representative location for determining the relevant position for a simple situation is given in Annex B for the case of a conductive coupling.

Annex C provides information on the operational principles of the electrical resistance (ER) probe.

7.2 Stray Current interference

7.2.1 Inductive and conductive coupling from remote sources

The worst-case assessment of interference in the case of inductive coupling and remote conductive coupling is obtained when placing the reference electrode at remote earth. The method for determining remote earth is described in ISO 18086:2019, Annex G. Since inductive coupling is usually associated with high isolation quality of the interfered structure, the positioning of the reference electrode above the interfered structure can be used as an approximation of the remote earth.

In such a configuration, the probe should ideally be installed next to the pipeline in the same bedding material as the pipeline, outside the influence of any field gradients generated by coating defects.

7.2.2 Conductive coupling from nearby sources

In the case of conductive coupling, the corrosive effect of the stray current is a result of the change in soil potential because of the electrical field generated by the stray current source. Therefore, the reference electrode or the probe shall be placed within the electrical field, taking into account worst-case situations. See Annex B for further information with respect to assessing worst-case conditions in the case of conductive coupling. The smallest distance of the pipeline to the interference source represents, in the case of conductive coupling, the portion of the pipeline with the largest level of interference. Therefore, the reference electrode, the coupon or the probe shall have a distance to the interference source that corresponds to this smallest distance. For specific conditions, this worst-case is given as follows:

— pipeline parallel to the rail: Reference electrode shall be placed above the pipeline;

— pipeline intersection with a rail: Reference electrode shall be placed above the pipeline with a distance to the outer rail that corresponds to the smallest distance between rail and pipeline;

— pipeline within the gradient of an anode bed: Reference electrode shall be placed above the pipeline at the location with the smallest distance between pipeline and anode.

There are cases where it is not possible to place the reference electrode, coupon or probe at the relevant location described above. In these cases, the electrical field distribution shall be assessed by measurement or calculation. The expected level of interference at the relevant position is then extrapolated based on the electrical field distribution to the position with the smallest distance between pipeline and interference source.

IEC 62128-2 and Reference [26] provide examples of a calculation method to determine the electrical field distribution from a rail. Based on these equations a correction for the electrode placement can be made.

7.3 Measurement of electrical parameters

7.3.1 Data acquisition systems

Sampling rates for potential, voltage and current measurements are typically between 0,1 s and 5 s for time variant values.

Coupon on/off measurements, for example, can require fast switching and sampling rates. Sampling rates shall be selected to enable accurate and meaningful measurement of the signal and phenomena under investigation.

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In the case of time variant DC interference such as tidal or telluric currents, longer intervals between the measurements can be used. The data acquisition system shall have an input impedance of at least 10 MΩ for voltage measurements.

7.3.2 Possible errors in AC measurements

ISO 18086[3] requires measured root mean square potential values as part of its risk assessment process. The r.m.s. values might not be correctly measured by some digital voltmeters if the AC waveform is not sinusoidal. Non-sinusoidal waveforms can occur if the load is non-linear (i.e. not predominantly resistive). Non-linear loads can include loads with inductive or capacitive components, e.g. switch mode power supplies, furnaces, industrial systems.

The harmonics produced when the load is non-linear distort the waveform and the triplen harmonics (3rd, 6th, 9th, etc.) can significantly increase the peak voltage.

To measure the r.m.s. potential value correctly, digital voltmeters with a true rms function shall be used.

7.3.3 Potential measurement

The pipeline potential measurements shall be performed by connecting the data logger to the pipeline and a reference electrode. The positioning of the reference electrode depends on the type of interference and is described in Clause 7.

If no direct connection to the interfered pipeline is possible, the measurement with respect to remote earth can be performed. In this case, instead of the pipeline connection, a reference electrode at remote earth is connected to the data logger.

7.3.4 Current measurement on probes

The effect of the inclusion of the shunt in the circuit that is being measured should not result in a measurement accuracy worse than +/–2,5 % because of the shunt. A typical value for the shunt is 10 Ω. Lower value shunts can be necessary to measure currents greater than 1 mA.

7.3.5 IR-free potential measurement on coupons or probes

All IR-drop measurement errors shall be minimized by calculation or measurement. In the case of conductive coupling, the ohmic drops in the ground shall be considered. Possible methods include at least one, or a combination, of the following:

— positioning of the reference electrode permanently or temporarily close to the coupon or probe surface;

— interruption of the protection current through the coupon/probe;

— taking readings when the interfering source is out of operation;

— calculation of the IR-drop caused by the protection current;

— calculation of the IR-drop caused by the interference source.

7.3.6 Duration of the measurement

The data acquisition shall be performed over a representative period. The following aspects require consideration:

— in the case of a constant interference (e.g. cathodic protection) this corresponds to at least 3 cycles with the interference source switched on and off;

— in the case of time variant interference from timetabled traction systems an initial measurement should be performed for at least 24 h. From this data, the periods of the maximum and minimum

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interference can be determined. Subsequent measurements can be performed over a shorter duration in the period of the highest interference;

— in the case of a time variant interference (e.g. telluric, HVAC) with unknown operational characteristics, the measurement should be performed over a time period of at least 24 h with the period of maximum and minimum interference included.

In the case of known and documented interference frequency, shorter recording times can be used.

7.3.7 Specific requirements for coupons or probes

In the case of AC interference, the use of 1 cm^2 coupons is required by Reference [3]. For DC stray current interference different sizes of coupon can be used[6].

The current flow through a probe is dependent on its spread resistance. For buried pipelines the spread resistance is dependent on the soil resistivity as well as change of soil composition because of the current flow through the steel surface. The coupon shall be polarized until the IR-free potential has stabilized before making the measurement. This will allow for the formation of representative conditions.

It is not always possible to install the probe in the original soil. In this case a documented (i.e. chemical characteristics) replacement soil can be chosen that represents worst-case conditions (see Reference [6]).

7.4 Corrosion rate measurement

Acceptance criteria for DC interference can be based on either direct measurement of corrosion rate (see 8.2) or general electrical parameters (see 8.1) or a combination of both.

The measurement of the external corrosion rate is direct evidence of the effectiveness of cathodic protection. In the case of a probe or coupon the positioning at the representative location as described in 7.2 is required.

8 Acceptance criteria for DC interference

8.1 Overview of criteria

The level of stray current interference shall be deemed acceptable if the criteria mentioned in Table 1 are met.

For structures that are not cathodically protected the baseline value used to assess anodic and cathodic interference levels is the potential measured during periods when the interference is not present [Corrosion potential (E_{cor})].

For structures that are cathodically protected the baseline value used to assess anodic and cathodic interference levels can be the on potential required to achieve effective cathodic protection [Reference potential (E_{ref})].

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Table 1 — Overview of criteria for the assessment of stray current interference

	Non-cathodically protected	Cathodically protected
Steel and cast-iron structures		
Anodic interference (i.e. when the potential is more anodic than the potential during the periods of non-interference) Time constant	Anodic potential shift (relative to E_{cor}) ΔE_a (IR-drop included): $\Delta E_a \leq 300$ mV ($\rho > 200$ Ω·m) or $\Delta E_a \leq 1{,}5$ mV(Ω·m)$^{-1}$•ρ (15 Ω·m ≤ $\rho \leq 200$ Ω·m) or $\Delta E_a \leq 20$ mV ($\rho < 15$ Ω·m) or anodic potential shift (relative to E_{cor}) $\Delta E_{a,IR\text{-}free}$ (IR- drop excluded): $\Delta E_{a,IR\text{-}free} \leq 20$ mV See 8.3.1.1.2	IR-free potential $E_{IR\text{-}free}$: $E_{IR\text{-}free} \leq E_p$ (E_p=protection potential according to Reference [7]) See 8.3.1.1.3
Cathodic interference Time constant	Cathodic potential shift ΔE_c: $\Delta E_c \leq 500$ mV (IR-drop included) See 8.3.1.2	
Anodic/cathodic interference Time variant	Average anodic potential shift (relative to E_{cor}) $\Delta E_{a,avg}$: $\Delta E_{a,avg} \leq \Delta E_a$ See 8.3.1.1.2	IR-free potential $E_{IR\text{-}free}$: $E_{IR\text{-}free} \leq E_p$ (E_p=protection potential according to Reference [7]) Shift of $E_{on,avg}$: $E_{on,avg} \leq E_{ref} - \Delta E_{a,avg}$ See 8.3.1.1.3[a]
	Average cathodic potential shift $\Delta E_{c,avg}$: $\Delta E_{c,avg} \leq 500$ mV (IR-drop included) See 8.3.1.2	
All conditions	Corrosion rate design value See 8.2	$v_{cor} \leq 0{,}01$ mm·a^{-1} See 8.2
Steel in concrete without cathodic protection		
Anodic interference Time constant Time variant	Anodic potential shift (relative to E_{cor}) ΔE_a: $\Delta E_a \leq 200$ mV see 8.4.1 $\Delta E_{a,avg} \leq 200$ mV see 8.4.2	
[a] Further information can be found in Annexes A and J.		

8.2 Corrosion rate

According to Reference [7] the pipe-to-electrolyte potential at which the corrosion rate is less than 0,01 mm per year (10 µm·a^{-1}) for carbon steel and cast iron is the protection potential, E_p. This corrosion rate is sufficiently low that corrosion will usually be acceptable for the design life. The corrosion rate criterion is therefore:

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v_{cor} ≤ 0,01 mm per year (10 µm·a^{-1})

It is possible that under certain interference conditions, this corrosion rate cannot always be met, and an accepted corrosion rate (design value) for a given design life shall therefore be considered. The accepted corrosion rate shall be justified and accepted by all interested parties.

For pipelines that are not cathodically protected, there is no active corrosion mitigation and the acceptable corrosion rate shall be the rate of corrosion used in the pipeline design.

For pipelines that are cathodically protected and subjected to external AC electrical interference[3], provides guidance on the corrosion risks associated with AC and combined AC and DC electrical interference.

These values can be measured in accordance with Annex B.

8.3 Criteria for steel and cast iron

8.3.1 Time constant interference

8.3.1.1 Anodic interference

8.3.1.1.1 General

The relevant anodic interference is evaluated from the anodic potential shift ΔE_a when the interfering source is in and out of operation.

8.3.1.1.2 Non-cathodically protected structures

Anodic interference shall be deemed acceptable if the criteria according to Table 2 are met.

Table 2 — Acceptable anodic potential shifts ΔE_a for buried or immersed steel or cast-iron structures that are not cathodically protected

Resistivity of the electrolyte (Ω·m)	Maximum anodic potential shift ΔE_a (mV) (including IR-drop)	Maximum anodic potential shift $\Delta E_{a,IR\text{-}free}$ (mV) (excluding IR-drop)
≥200	300	20
15 to 200	1,5 mV (Ω·m)$^{-1}$ • ρ [a]	20
<15	20	20

[a] ρ in Ω·m.

8.3.1.1.3 Cathodically protected structures

Anodic interference shall be deemed acceptable if the IR-free potential of the structure, $E_{IR\text{-}free}$, meets the criteria for the protection potential, E_p, given by Reference [7].

8.3.1.2 Cathodic interference

The relevant cathodic interference is evaluated from the cathodic potential shift ΔE_c when the interfering source is in and out of operation. This value is determined by the difference of the potential measured with the interference source operating minus the potential with the interference source off.

Cathodic potential shifts, ΔE_c, due to cathodic interference on a certain part of a structure imply that there exist other parts that are subject to anodic interference, i.e. an anodic potential shift ΔE_a. If very negative potential shifts (e.g. ΔE_c > 500 mV, IR-drop included) are measured, it is recommended to

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identify areas with anodic potential shifts to confirm conformity with criteria mentioned in 8.3.1.1.2 and 8.3.1.1.3.

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

8.3.2 Time variant interference

8.3.2.1 General

Subclause 8.3.2 covers time variant interference, e.g. due to DC operated railways, telluric currents and tidal effects.

The time (t) variations of the interference signal, e.g. $E(t)$ or $E_{on}(t)$, are considered to consist of successive intervals with anodic, $E_a(t)$, and cathodic, $E_c(t)$, polarization. The terms "anodic" and "cathodic" are defined with respect to a selected reference level E_{ref} (see Annex J) The interference signal is monitored over a representative duration.

$E(t)$ or $E_{on}(t)$ are measured with the reference electrode placed according to Annex B and without any coupon placed nearby.

For installed coupons, the assessment is based on the measurement of the coupon current (I_{cpn}), from which the current density (J_{cpn}) is calculated. Anodic and cathodic current densities that are due to time variant interference are defined with respect to a selected reference level J_{ref} (see Annex J).

8.3.2.2 Time variant anodic interference

8.3.2.2.1 Non-cathodically protected structures

The average anodic interference, $\Delta E_{a,avg}$, is assessed from a representative measurement of $E(t)$ showing intervals when the interfering source is in and out of operation.

A reference potential E_{ref} is evaluated from the interval when the interfering source is out of operation, e.g. during the night.

Intervals of anodic interference are identified from $E_a(t) = E(t) - E_{ref} > 0$, which had been measured over a representative time interval (see 7.3.6). The average anodic potential shift, $\Delta E_{a,avg}$, is evaluated from the average of $E_a(t)$ over the representative time interval.

Anodic interference shall be deemed acceptable if $\Delta E_{a,avg}$ is within the limits defined for ΔE_a (see 8.3.1.1.2).

8.3.2.2.2 Cathodically protected structures

One of these four methods can be used to determine whether the time variant interference is acceptable:

a) Time variant interference shall be deemed acceptable if the IR-free potential of the structure, E_{IRfree}, is within the limits for the protection potential, E_p, given by Reference [7]. The IR-free potential can be measured with the use of coupons.

b) The reference on-potential E_{ref}, at which effective CP in accordance with Reference [7] is just achieved, is determined during the period without interference (e.g. during the night in the absence of train operation). Subsequently the average anodic potential shift $\Delta E_{a,avg}$ is determined over a representative period of time, typically 24 h, with the CP system in continuous operation (no switching of the rectifiers). A sufficient level of cathodic protection is ensured, if the following equation is satisfied:

$$E_{on,avg} \leq E_{ref} - \Delta E_{a,avg}$$

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