
**Petroleum, petrochemical and natural
gas industries — Cathodic protection
of pipeline systems —**

**Part 1:
On-land pipelines**

*Industries du pétrole, de la pétrochimie et du gaz naturel —
Protection cathodique des systèmes de transport par conduites —
Partie 1: Conduites terrestres*

Contents

	Page
Foreword	vi
Introduction	vii
1 Scope	1
2 Normative references	1
3 Terms and definitions	2
4 Symbols and abbreviations	5
4.1 Symbols.....	5
4.2 Abbreviations.....	7
5 CP personnel competence	7
6 Cathodic protection criteria	8
6.1 General.....	8
6.2 Protection potentials.....	8
6.3 Alternative methods.....	10
6.3.1 100 mV cathodic potential shift.....	10
6.3.2 Other methods.....	10
6.4 Criteria in the presence of a.c.....	10
7 Pre-requisites for the application of cathodic protection	10
7.1 General.....	10
7.2 Electrical continuity.....	10
7.3 Electrical isolation.....	11
7.3.1 General.....	11
7.3.2 Locations.....	11
7.3.3 Isolating joints.....	11
7.3.4 Internal corrosion risks at isolating joints.....	12
7.3.5 Contacts between metallic structures.....	13
7.3.6 Electrical earthing system.....	13
7.4 Lightning and overvoltage protection.....	14
7.5 Coating.....	15
7.5.1 General.....	15
7.5.2 Factory-applied coatings.....	15
7.5.3 Field joint coatings.....	15
7.5.4 Coating for trenchless pipelines.....	15
7.5.5 Air to electrolyte interface.....	16
7.5.6 Compatibility of coatings and wraps with cathodic protection.....	16
7.5.7 Thermal insulation.....	16
7.5.8 Reinforced concrete weight coating.....	17
7.6 Selection of pipe trench backfill material.....	17
7.7 Buried casings for pipelines.....	17
7.7.1 General.....	17
7.7.2 Casings that shield cathodic protection current.....	17
7.7.3 Casings that pass cathodic protection current.....	18
7.8 Equipment for the reduction of a.c. interference.....	18
7.9 Equipment for the mitigation of d.c. interference.....	18

8	Basic requirements for cathodic protection design	18
8.1	General.....	18
8.2	Basic information for cathodic protection design.....	19
8.3	Contents of cathodic protection design report.....	20
8.4	Cathodic protection current demand.....	20
8.4.1	Calculation of the theoretical total current demand.....	20
8.4.2	Current demand based on coating breakdown factors.....	21
8.4.3	Current demand based on current density values for coated pipelines.....	22
8.5	Cathodic protection equipment.....	23
8.5.1	Cathodic protection cables.....	23
8.5.2	Cable connection.....	24
8.5.3	Precautions to respect for distribution boxes and test stations.....	25
8.6	Temporary protection.....	26
8.7	Specific case of existing pipelines.....	26
8.7.1	General.....	26
8.7.2	Parallel pipelines.....	27
8.7.3	Parallelism or crossing with a.c. power systems.....	27
8.8	Trenchless installation methods.....	27
9	Impressed current stations	28
9.1	General.....	28
9.2	Power supply.....	28
9.3	Groundbeds.....	29
9.3.1	General.....	29
9.3.2	Deep-well groundbeds.....	29
9.3.3	Shallow groundbeds.....	30
9.3.4	Impressed-current anodes and conductive backfill.....	31
9.4	Output control.....	32
9.4.1	General.....	32
9.4.2	Current distribution for multiple pipelines.....	32
9.4.3	Potential control.....	33
10	Galvanic anode systems	33
10.1	General.....	33
10.2	Design requirements.....	34
10.3	Zinc anodes.....	34
10.4	Magnesium anodes.....	35
10.5	Design of the anode system.....	37
10.6	Anode backfill.....	38
10.7	Cables and cable connections.....	39
10.8	Anode installation.....	39
11	Monitoring facilities	39
11.1	General.....	39
11.2	Locations of test stations.....	39
11.3	Description of test stations.....	40
11.4	Use of probes and coupons.....	40
11.5	Bonding to other pipelines.....	41
11.6	Test facilities at cased crossings.....	41
11.7	Test facilities at isolating joints.....	41
11.8	Line current monitoring test stations.....	41
11.9	Drain-point test facilities.....	41
11.10	Miscellaneous monitoring facilities.....	41

12	Commissioning	41
	12.1 General.....	41
	12.2 Preliminary tests.....	42
	12.3 Start up.....	43
	12.3.1 Impressed current stations.....	43
	12.3.2 Galvanic anodes.....	43
	12.3.3 Drainage stations.....	44
	12.3.4 Test stations.....	44
	12.4 Verification of cathodic protection effectiveness.....	44
	12.4.1 General.....	44
	12.4.2 Measurements of d.c. potential and a.c. voltage.....	44
	12.4.3 Current measurements.....	45
	12.4.4 Adjustments.....	45
	12.5 Commissioning report.....	45
	12.5.1 Installation documentation.....	45
	12.5.2 Commissioning measurements.....	45
13	Monitoring, inspection, and maintenance	46
	13.1 General.....	46
	13.2 Implementation of inspection.....	47
	13.3 Periodicities of inspection.....	47
	13.4 Remote monitoring.....	50
	13.5 Specialized surveys.....	50
	13.6 Monitoring plan.....	50
	13.7 Monitoring equipment.....	50
	13.8 Maintenance and repair.....	51
14	Documentation	51
	14.1 Design documentation.....	51
	14.1.1 General.....	51
	14.1.2 Construction details and installation procedures.....	52
	14.2 Commissioning documentation.....	53
	14.3 Operating and maintenance documentation.....	53
	14.3.1 General.....	53
	14.3.2 Inspection and monitoring data.....	54
	14.3.3 Maintenance records.....	54
	Annex A (normative) Cathodic protection measurements	55
	Annex B (normative) Electrical interference	63
	Annex C (informative) Fault detection of impressed-current systems during operation	67
	Annex D (informative) Description of specialized surveys	69
	Annex E (informative) Attenuation of protection	76
	Annex F (informative) Electrical tests for isolating joints before installation	79
	Bibliography	80

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: [Foreword - Supplementary information](#)

The committee responsible for this document is ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 2, *Pipeline transportation systems*.

This second edition cancels and replaces the first edition (ISO 15589-1:2003), which has been technically revised with the following changes:

- cathodic protection criteria have been extended with further clarification on the application of the criteria;
- requirements for design have been more detailed and periodicities for inspection of cathodic equipment have been enlarged, and the option for remote monitoring added;
- requirements for measurements and testing during commissioning have been further detailed.

ISO 15589 consists of the following parts, under the general title *Petroleum, petrochemical and natural gas industries — Cathodic protection of pipeline systems*:

- *Part 1: On-land pipelines*
- *Part 2: Offshore pipelines*

Introduction

Pipeline cathodic protection is achieved by the supply of sufficient direct current to the external pipe surface, so that the steel-to-electrolyte potential is lowered to values at which external corrosion is reduced to an insignificant rate.

Cathodic protection is normally used in combination with a suitable protective coating system to protect the external surfaces of steel pipelines from corrosion.

It is necessary that users of this part of ISO 15589 be aware that further or differing requirements can be needed for individual applications. This part of ISO 15589 is not intended to inhibit the use of alternative equipment or engineering solutions for the individual application. This can be particularly applicable where there is innovative or developing technology. It is necessary that, where an alternative is offered, any variations from this part of ISO 15589 be identified and documented.

Petroleum, petrochemical and natural gas industries — Cathodic protection of pipeline systems —

Part 1: On-land pipelines

1 Scope

This part of ISO 15589 specifies requirements and gives recommendations for the pre-installation surveys, design, materials, equipment, installation, commissioning, operation, inspection, and maintenance of cathodic protection systems for on-land pipelines, as defined in ISO 13623 or EN 14161 for the petroleum, petrochemical, and natural gas industries, and in EN 1594 or EN 12007-1 and EN 12007-3 used by gas supply industries in Europe.

All contents of this part of ISO 15589 are applicable to on-land pipelines and piping systems used in other industries and transporting other media such as industrial gases, waters, or slurries.

This part of ISO 15589 applies to buried pipelines, landfalls of offshore pipeline sections protected by on-shore based cathodic protection installations, and to immersed sections of on-land pipelines such as river or lake crossings.

This part of ISO 15589 specifies requirements for pipelines of carbon steel, stainless steel, cast iron, galvanized steel, or copper. If other pipeline materials are used, the criteria to apply are defined under the responsibility of the pipeline operator.

This part of ISO 15589 does not apply to pipelines made of reinforced concrete for which EN 12696 can be applied.

NOTE Special conditions sometimes exist where cathodic protection is ineffective or only partially effective. Such conditions can include shielding (e.g. disbanded coatings, thermal-insulating coatings, rocky soil, etc.) and unusual contaminants in the electrolyte.

2 Normative references

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

ISO 8044, *Corrosion of metals and alloys — Basic terms and definitions*

ISO 10012, *Measurement management systems — Requirements for measurement processes and measuring equipment*

ISO 13623, *Petroleum and natural gas industries — Pipeline transportation systems*

ISO 13847, *Petroleum and natural gas industries — Pipeline transportation systems — Welding of pipelines*

ISO 21809 (all parts), *Petroleum and natural gas industries — External coatings for buried or submerged pipelines used in pipeline transportation systems*

IEC 60079-10-1, *Explosive atmospheres — Part 10-1: Classification of areas — Explosive gas atmospheres*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

EN 1594, *Gas infrastructure — Pipelines for maximum operating pressure over 16 bar — Functional requirements*

EN 12007-3, *Gas supply systems — Pipelines for maximum operating pressure up to and including 16 bar — Part 3: Specific functional recommendations for steel*

EN 12496, *Galvanic anodes for cathodic protection in seawater and saline mud*

EN 14161 *Petroleum and natural gas industries — Pipeline transportation systems (ISO 13623:2009 modified)*

EN 50164-3, *Lightning Protection Components (LPC) — Part 3: Requirements for isolating spark gaps*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 8044 and the following apply.

- 3.1 anode backfill**
added material immediately surrounding a buried anode
- 3.2 bond**
metal conductor, usually copper, connecting two points on the same or on different structures
- 3.3 cathodic protection system**
all active and passive components associated with the provision of active external corrosion protection and its monitoring

Note 1 to entry: Cathodic protection is obtained either by impressed current or by galvanic anodes using one or more stations.

Note 2 to entry: Impressed current and galvanic anode systems consist of all the equipment necessary for the application of cathodic protection, such as impressed current stations, galvanic anodes, bonds, and isolating joints.

- 3.4 coupon**
metal sample of defined dimensions made of a metal equivalent to the metal of the pipeline
- 3.5 coating breakdown factor**
ratio of current density required to polarize a coated steel surface as compared to a bare steel surface
- 3.6 d.c. decoupling device**
equipment that provides a low-impedance path for a.c. and high resistance for d.c.

EXAMPLE Polarization cells, capacitors, or diode assemblies.

- 3.7 drain point**
location of the cable connection to the protected pipeline through which the protective current returns to its source
- 3.8 drainage**
transfer of stray current between structures by means of a deliberate bond

Note 1 to entry: See EN 50162 for drainage devices (direct drainage bond, resistance drainage bond, unidirectional drainage bond, and forced drainage bond).

- 3.9 drainage station**
equipment and materials required to provide drainage of stray currents from affected systems

3.10**galvanic anode**

electrode that provides current for cathodic protection by means of galvanic coupling

3.11**galvanic anode station**

equipment and materials required to provide cathodic protection by the use of galvanic anodes

Note 1 to entry: Such materials and equipment include galvanic anodes and cables.

3.12**geological cell**

corrosion cell constituted between two different parts of a single metallic pipeline in contact with different soils

3.13**groundbed**

system of buried or immersed galvanic or impressed current anodes

3.14**impressed current anode**

electrode that provides current for cathodic protection by means of impressed current

3.15**impressed current station**

equipment and materials required to provide cathodic protection by impressed current

Note 1 to entry: Such materials and equipment include impressed current anodes, cables, and a d.c. source.

3.16**instant-OFF potential**

OFF potential measured with a short delay after interruption with the aim of approaching as much as possible the IR-free potential

Note 1 to entry: A typical delay for direct measurements on pipeline is about 300 ms to prevent the influence of voltage spikes. On coupons, shorter delays are used.

3.17**IR drop**

voltage that is the product of all currents flowing through the cathodic protection circuit and the resistance of the current path (mainly the electrolyte and the pipeline)

Note 1 to entry: This is derived from Ohm's law ($U = I \times R$).

3.18**IR-free potential****polarized potential**

pipe to electrolyte potential without the voltage error caused by the IR drop due to the protection current or any other current

3.19**isolating joint**

electrically insulating component inserted between two lengths of pipe to prevent electrical continuity between them

EXAMPLE Monobloc isolating joint, isolating flange.

3.20

isolating spark gap

ISG

component with discharge distance for isolating electrically conductive installation sections

Note 1 to entry: In the event of lighting strike, the installation sections are temporarily connected conductively as the result of response of the discharge.

3.21

local earthing

earthed metallic electrode not directly electrically connected to any other main earthing system

3.22

measuring point

location where the actual potential measurement takes place

Note 1 to entry: In the case of pipe-to-electrolyte potential measurement, this refers to the location of the reference electrode.

3.23

ON potential

pipe-to-electrolyte potential measured while the cathodic protection system is continuously operating

3.24

OFF potential

pipe-to-electrolyte potential measured after interruption of all sources of applied cathodic protection current with the aim of approaching an IR-free potential

Note 1 to entry: The delay before measurements varies according to the circumstances.

3.25

pipe-to-electrolyte potential

difference in potential between a pipeline (or coupon) and a specified reference electrode in contact with the electrolyte at a point sufficiently close to, but without actually touching, the pipeline

3.26

pitting resistance equivalent number

PREN

number, developed to reflect and predict the pitting resistance of a stainless steel, based upon the proportions of Cr, Mo, W, and N in the chemical composition of the alloy

3.27

polarization

change of pipe-to-electrolyte potential caused by the application of an external electrical current

3.28

probe

device incorporating a coupon that provides measurements of parameters used to assess the effectiveness of cathodic protection and/or corrosion risk

3.29

protection potential

pipe-to-electrolyte potential at which the metal corrosion rate is acceptable for the pipeline

3.30

reference electrode

electrode, having a stable and reproducible potential that is used as a reference in the measurement of electrode potentials

[SOURCE: ISO 8044]

3.31**remote earth**

part of the electrolyte in which no measurable voltages, caused by current flow, occur between any two points

Note 1 to entry: This condition generally prevails outside the zone of influence of an earth electrode, an earthing system, an anode groundbed, or a protected pipeline.

3.32**rock jacket coating**

coating that provides mechanical protection to the pipeline and is applied as bendable flexible coating

3.33**stray current**

current flowing through paths other than the intended circuits

[SOURCE: Adapted from ISO 8044]

3.34**surge protective device****SPD**

device intended to limit transient overvoltages and direct surge currents

Note 1 to entry: It contains at least one nonlinear component.

[SOURCE: IEC 62305-1]

3.35**telluric current**

current in the earth as a result of geomagnetic fluctuations

3.36**test station****monitoring station**

installation that provides measuring and test facilities

Note 1 to entry: Such installations include cabling and pipeline connections.

3.37**utilization factor**

fraction of the anodic material weight of a galvanic anode that can be consumed before the anode ceases to provide the minimum required current output

4 Symbols and abbreviations**4.1 Symbols**

D_a	anode diameter
D_b	backfill diameter
ε	electrochemical capacity of the anode material
E	potential measured at the metal/electrolyte interface
ΔE	potential shift due to cathodic protection current measured against a remote reference electrode
E_a	design closed-circuit potential of a galvanic anode

ISO 15589-1:2015(E)

E_c	design protection potential (minimum negative potential)
E_{cor}	free corrosion potential (also called natural potential)
E_{IRfree}	IR free potential
E_l	limiting critical potential
E_{ON}	ON-potential
E_{OFF}	OFF-potential
E_p	protection potential
f_c	coating breakdown factor
f_f	final coating breakdown factor
f_i	initial coating breakdown factor
Δf	average yearly increase in the coating breakdown factor
I_{tot}	total current demand
I_{af}	actual end-of-life individual anode current output
I_{cf}	total current demand for the cathodic protection of a specific pipeline section at the end of life (for maximum coating breakdown factor)
I_{cm}	mean current demand
I_f	required end-of-life individual anode current output
j	current density for bare steel
j_c	current density for coated pipelines
k	contingency factor
L	length of the pipeline
m	total net anode mass
m_a	individual net anode mass
n	number of anodes
r_{co}	average coating resistance
R_a	total circuit resistance for a galvanic anode cathodic protection system (assumed to be equivalent to the anode resistance)
$R_{a/b}$	anode resistance relative to backfill
$R_{b/s}$	backfill bed resistance relative to the natural electrolyte
ρ	resistivity of an electrolyte
T	temperature
t_{dl}	design life

<i>U</i>	<i>voltage</i>
<i>u</i>	utilization factor

4.2 Abbreviations

a.c.	alternating current
ACVG	alternating current voltage gradient
CIPS	close interval potential survey
CP	cathodic protection
CSE	copper–copper sulphate (saturated) reference electrode
d.c.	direct current
DCVG	direct current voltage gradient
ER	electrical resistance
FBE	fusion-bonded epoxy
LPC	lightning protection component
MMO	mixed metal oxide
PREN	pitting resistance equivalent numbers
SCC	stress corrosion cracking
SCE	saturated calomel reference electrode
SRB	sulphate reducing bacteria
UV	ultraviolet
3LPE	three layer polyethylene
3LPP	three layer polypropylene

5 CP personnel competence

Personnel who undertake the design, supervision of installation, commissioning, supervision of operation, measurements, monitoring, and supervision of maintenance of cathodic protection systems shall have the appropriate level of competence for the tasks undertaken.

EN 15257 or NACE Cathodic Protection Training and Certification Programme constitute suitable methods of assessing and certifying competence of cathodic protection personnel.

Competence of cathodic protection personnel to the level appropriate for tasks undertaken should be demonstrated by certification in accordance with prequalification procedures such as EN 15257, NACE Cathodic Protection Training and Certification Programme, or by any other equivalent scheme.

6 Cathodic protection criteria

6.1 General

The pipe-to-electrolyte potential at which the corrosion rate is less than 0,01 mm per year for carbon steel and cast iron is the protection potential, E_p . This corrosion rate is sufficiently low so that corrosion will be acceptable for the design life. The criterion for CP is therefore, given by the condition in Formula (1):

$$E_{IRfree} \leq E_p \quad (1)$$

where

E_p is the protection potential criterion;

E_{IRfree} is the potential at the metal/electrolyte interface, i.e. the potential that is free from the IR drop in the corrosive environment (IR-free potential, also commonly known as “polarized potential”).

The protection potential of a metal depends on the corrosive environment (electrolyte) and on the type of metal used.

Application of potentials that are too negative can result in cathodic over-protection leading to coating disbondment and blistering and hydrogen embrittlement of some metals.

The IR-free potential, E_{IRfree} , shall not be more negative than the limiting critical potential, E_l .

In such cases, the criterion for CP is given by the condition in Formula (2):

$$E_l \leq E_{IRfree} \leq E_p \quad (2)$$

6.2 Protection potentials

The IR-free potential, E_{IRfree} , shall meet the criteria given by Formula (1) and, if applicable, Formula (2). [Table 1](#) presents free corrosion potentials, E_{COR} , protection potentials, E_p , and limiting critical potentials, E_l , for different metals in different environmental conditions.

Table 1 — Free corrosion potentials, protection potentials, and limiting critical potentials of common metallic materials in soils and waters (except seawater) measured against CSE

Metals or alloys	Environmental conditions	Free corrosion potential range (indicative values) E_{cor} V	Protection potential (IR-free) E_p V	Limiting critical potential (IR-free) E_l V
Carbon steels, low alloyed steels and cast iron	Soils and waters in all conditions except those hereunder described	-0,65 to -0,40	-0,85	a
	Soils and waters at $40\text{ °C} < T < 60\text{ °C}$	—	b	a
	Soils and waters at $T > 60\text{ °C}$ ^c	-0,80 to -0,50	-0,95	a
	Soils and waters in aerobic conditions at $T < 40\text{ °C}$ with $100 < \rho < 1\ 000\ \Omega\cdot\text{m}$	-0,50 to -0,30	-0,75	a
	Soils and waters in aerobic conditions at $T < 40\text{ °C}$ with $\rho > 1\ 000\ \Omega\cdot\text{m}$	-0,40 to -0,20	-0,65	a
	Soils and waters in anaerobic conditions and with corrosion risks caused by Sulfate Reducing Bacteria activity	-0,80 to -0,65	-0,95	a
Austenitic stainless steels with PREN < 40	Neutral and alkaline soils and waters at ambient temperatures	-0,10 to + 0,20	-0,50	d
Austenitic stainless steels with PREN > 40		-0,10 to + 0,20	-0,30	-
Martensitic or austeno-ferritic (duplex) stainless steels		-0,10 to + 0,20	-0,50	e
All stainless steels	Acidic soils and waters at ambient temperatures	-0,10 to + 0,20	e	e
Copper	Soils and waters at ambient temperatures	-0,20 to 0,00	-0,20	-
Galvanized steel		-1,10 to -0,90	-1,20	
NOTE 1 All potentials are IR free and refer to a copper/saturated copper sulfate reference electrode, $E_{Cu} = E_H - 0,32\text{ V}$.				
NOTE 2 During the lifetime of the pipeline, any possible changes of resistivity of the medium around the pipeline are to be taken into account.				
^a To prevent hydrogen embrittlement on high strength non alloyed and low alloyed steels with designed yield strength exceeding $550\text{ N}\cdot\text{mm}^{-2}$, the critical limit potential shall be documented or determined experimentally.				
^b For temperatures $40\text{ °C} \leq T \leq 60\text{ °C}$, the protection potential may be interpolated linearly between the potential value determined for 40 °C ($-0,65\text{ V}$, $-0,75\text{ V}$, $-0,85\text{ V}$ or $-0,95\text{ V}$) and the potential value for 60 °C ($-0,95\text{ V}$).				
^c The risk of high pH stress corrosion cracking increases with increase of temperature.				
^d In case of presence of any martensitic or ferritic phase (e.g. due to hardening), the risk of hydrogen embrittlement should be determined by documentation or experimentally.				
^e Determination by documentation or experimentally.				

To prevent disbondment and/or blistering of the coating, the limiting critical potential, E_l , should not be more negative than $-1,20\text{ V}$ (CSE) for the currently used pipeline coatings.

6.3 Alternative methods

6.3.1 100 mV cathodic potential shift

If the criteria defined in [Table 1](#) cannot be achieved, a minimum cathodic potential shift of 100 mV is considered as an acceptable alternative method to reduce the corrosion rate (see NACE Publication n°35108[1]). A residual corrosion rate less than 0,01 mm/y might not be achieved. The formation or decay of potential shift shall be measured in accordance with the method defined in [Annex A](#).

The application of the 100 mV potential shift shall be avoided at operating temperatures above 40 °C, in SRB-containing soils, when interference currents, equalizing currents, or telluric currents might be present, or when there is a risk of external stress corrosion cracking. Furthermore, the potential shift method shall not be used in the case of pipelines connected to or consisting of mixed metal components.

6.3.2 Other methods

Alternative methods may be used if it can be demonstrated that the control of corrosion is achieved.

6.4 Criteria in the presence of a.c.

In locations where a.c. interference is possible, measurements of a.c. voltage and/or current density shall be carried out to evaluate the level of the a.c. influence.

In the presence of a.c. voltage on the pipeline, the protection criteria defined in [Table 1](#) shall be fulfilled although they do not necessarily provide protection against a.c. corrosion. The IR-free potential, E_{IRfree} , shall meet the criterion given by Formula (1).

EN 15280 gives guidelines for the a.c. corrosion likelihood and defines detailed criteria that may be applied.

7 Pre-requisites for the application of cathodic protection

7.1 General

For application of cathodic protection, the pipeline, or section of the pipeline to be protected, shall be electrically continuous. The pipeline should be coated and electrically isolated from other structures and earthing systems. Justification shall be provided if the pipeline is not electrically isolated from other structures and earthing systems.

NOTE Coatings are universally applied to buried pipelines to provide the primary corrosion protection with cathodic protection to protect areas of coating damage. Coatings reduce the overall cathodic protection current requirement and, as a consequence, the risk of interference to adjacent buried structures.

7.2 Electrical continuity

The electrical continuity of the pipeline, or any section of the pipeline to be protected, shall achieve a low longitudinal resistance and the components which may increase the longitudinal resistance of the pipeline shall be short-circuited, e.g. by using cables or low-resistance metal bonds with a suitable cross sectional area.

On non-welded pipelines, the electrical continuity shall be achieved on the length to be protected by the installation of permanent bonds across the high-resistance mechanical connectors using reliable bond attachment methods. The continuity of non-welded pipelines shall be checked by carrying out resistance and potential measurements.

When necessary, bonding may be carried out across isolating devices for measurement or other purposes. If it is necessary that electrical continuity be established permanently, this bonding should be done in a test station.

7.3 Electrical isolation

7.3.1 General

Metallic contacts or resistive contacts between the pipeline and other structures, or direct connection to earthing systems, should be avoided; otherwise, the corrosion risk can be increased.

For this reason, pipelines should be electrically isolated from foreign structures including compressor stations, pump stations, pressure reducing, metering and delivery stations, water pumping and storage facilities, wellsites, offshore pipelines and structures, terminals and processing facilities, and at interfaces with other pipelines.

Electrical isolation can also be installed to divide the system into sections, e.g. in stray current areas.

Isolation should be achieved by installation of isolating joints (monolithic isolation joints or isolating flange kits) or non-conductive pipe sections.

If electrical isolation is not possible, then the cathodic protection design shall provide for sufficient current and effective current distribution to ensure that the pipeline is cathodically protected without adverse effect on other structures.

If there is a contact between the protected pipeline and any other less electronegative structure, EN 14505 considers they constitute a complex structure and gives recommendations that can help in that case.

7.3.2 Locations

The location of the electrical isolation points should be carefully considered, particularly in the case of d.c. stray current. This requires, for example, detailed measurements and analysis of the electrolyte surface gradients (see EN 50162 for further guidance).

Electrical isolation can be required

- between pipeline sections consisting of different metallic materials,
- at the extremities of the pipeline,
- at significant changes in electrolyte resistivity,
- on pipelines requiring different cathodic protection systems,
- on pipelines with different current density requirements,
- in areas influenced by stray currents, a.c., or telluric currents,
- on some pipeline networks to facilitate the cathodic protection maintenance or measurements, and
- at interfaces with unprotected structures or earthed equipment.

In the case of distribution systems, electrical isolation shall be installed at the interface with customer facilities.

7.3.3 Isolating joints

The mechanical design, materials, dimensions, and construction of the isolating joints shall meet the requirements of ISO 13623, EN 14161, EN 1594 or EN 12007-3, as applicable.

Monobloc isolation joints should be used wherever possible. They can be installed above-ground, in a pit or buried.

Monobloc isolation joints should be electrically tested before installation.

NOTE 1 Electrical tests are proposed in [Annex F](#).

NOTE 2 Installing the isolation joint above ground provides the advantage of easier visual, electrical, and ultrasonic inspection. On the other hand, buried isolating joints are less exposed to mechanical or fire hazards, voluntary or involuntary damage, and can prevent the product inside the pipeline from freezing (sometimes referred to as “frost-proof grounding”).

NOTE 3 Installing an isolating joint in a pit provides the advantages of a buried isolation joint but with the added risk of gas entrapment. For this reason, local regulations can prevent installation of an isolation joint in a pit.

When a pipeline is connected to above-ground facilities, an above-ground isolating joint ensures that cathodic protection is applied to the entire buried section. If the isolation joint is buried, then the pipeline operator shall take additional measures for corrosion protection of the section of the pipeline that is isolated from the main cathodic protection system.

If multiphase fluids containing a significant percentage of water are transported in the pipeline, installation of the isolating joint on a vertical or angled transition section should be considered to prevent a continuous water phase inside the pipeline becoming the source of internal corrosion (see [7.3.4](#)).

Buried isolation joints shall be externally coated with materials that are compatible with the coating applied to the pipeline.

Isolating flanges are subject to degradation by atmospheric weathering, dirt, and moisture ingress and shall be protected against ingress of dirt and moisture by the use of flange protectors or viscoelastic compounds.

A major cause of failure of isolating flanges is poor installation techniques. To reduce this risk, the manufacturer's instructions should be followed or factory preinstalled kits utilized.

Principal installation errors are

- over-tightening of the flange bolts (isolating flanges require a lower tightening torque than flanges without isolating gaskets),
- incorrect alignment of flange faces, and
- improper surface preparation of flange faces.

The isolation materials shall be designed to withstand service conditions (e.g. transported medium, temperature, pressure, mechanical stress) and shall have an appropriate dielectric strength. Other important properties of the isolating flange kit include mechanical (e.g. flexural and tensile strength, etc.), isolation efficiency, and water absorption.

Isolating joints shall be installed in such a manner as to eliminate the risk of accidental shorting.

To avoid damage from high voltages due to lightning strikes or a.c. fault currents caused by electric power lines, protective devices shall be considered (e.g. appropriate isolating spark gap, surge protective device, and appropriate electrical earthing).

Isolating joints installed in areas classified as hazardous in accordance with EN 60079-10-1 shall conform to the certification and operational requirements of the hazardous area.

Isolating joints shall be provided with accessible test facilities.

7.3.4 Internal corrosion risks at isolating joints

In pipelines carrying fluids with a separate water phase, there is a risk of internal corrosion caused by current leaving the internal surface of the pipe close to the isolating joint on the side that has a less negative internal potential (anodic side). This is mainly dependent on the conductivity of the fluid and the voltage between both sides of the isolating joint.

To prevent or mitigate this internal corrosion risk, a lining (internal coating with an electrically isolating material) should be applied on the side of the pipeline with the more negative internal potential (cathodic side).

The length of the section being lined internally increases with increasing electrolyte conductivity, increasing pipeline diameter and increasing voltage on the sides of the isolating joint. If there is no prior knowledge from previous experience, then the length of pipeline being lined should be determined by calculations or tests.

The length of internal coating can be determined by defining an internal ohmic resistance of the internal fluid. This assessment can be made using simulation software or by calculation (Ohm's law), and shall be documented. This study shall be made considering the fluid resistivity, the potential drop between each part of the isolating joint, and the absence of external coating defect on the anodic side of the pipeline.

NOTE 1 Based on feedback and experience, a value of 100 Ω for the internal ohmic resistance is commonly used for the evaluation of the length of the internal coating.

NOTE 2 For long lengths of lining, an entire pipe length lined in a factory is generally used.

In practice, if both sides of isolating joints are lined, the length of the lining on the cathodic side shall be at least the calculated length.

NOTE 3 When custom made asymmetrical lined isolating joints are used, the risk incurred by installing the longer liner on the wrong side of the isolating joints can be significant.

The lining should be of a type that does not deteriorate when in contact with the internal fluid, especially in the case of a lining exposed to salt water.

An alternative to internal lining is to install a sacrificial steel pipe spool piece next to the isolating joint on the side that has a less negative internal potential (anodic pipeline side). The spool piece should be periodically inspected to monitor the progress of internal corrosion and replaced in time to prevent leakage.

7.3.5 Contacts between metallic structures

Where entries, restraints, supports, and anchors are made of concrete, there should be no contact (direct or resistive) between reinforcing steel and the protected pipeline. For this reason, a wall entry fitting made of insulating material should be provided and a high-quality coating should be applied to the protected pipeline. The possibility of shielding effect shall be considered.

Where the pipeline crosses a bridge above ground or enters a tunnel and includes isolating joints at each end of the bridge or the tunnel, the pipe between isolating joints may be equipotentially bonded to the bridge or the tunnel to provide protection from inadmissible touch potentials. In order to provide cathodic protection to the pipeline on either side of the bridge or the tunnel from a common cathodic protection system, an equipotential bond is required to connect the pipeline on both sides of the bridge or the tunnel.

If the pipeline crosses a bridge in a service trough containing an electrolyte (e.g. sand), the pipe may be cathodically protected by galvanic anodes (e.g. magnesium ribbon) and not connected to the bridge.

If there are no isolating joints, then the pipe shall be electrically isolated from the metallic parts of the bridge or the tunnel. This is especially important in the case of metal bridges carrying d.c. traction systems.

7.3.6 Electrical earthing system

Electrical earthing of devices installed on the protected pipeline can be required for safety reasons or pipeline earthing can be required to mitigate the effect of induced electrical voltages.

If an earthing system is required, it shall be made compatible with the cathodic protection system. When allowed by regulations, this may be achieved by installing suitably rated d.c. decoupling devices in the earthing circuit. Local earthing using zinc or galvanized earth electrodes directly connected to the pipeline may be used, but there can still be future adverse effects on the cathodic protection.

NOTE 1 These adverse effects on cathodic protection effectiveness are due to one or both of the following:

ISO 15589-1:2015(E)

- the resistance of local earth, with respect to remote earth, can be much lower than the resistance of coating defects, which results in reduced CP current at the coating defect;
- zinc or galvanized steel potential can drift with time towards less negative potentials.

If earthing is being installed to mitigate the effect of a.c. voltages on the pipeline, the earthing locations should be established through a specific study and detailed design.

NOTE 2 EN 15280 and EN 50443 provide guidance on the corrosion and safety aspects related to a.c. influences.

Detection and control of electrical interference shall be in accordance with [Annex B](#).

When an earthing (local or remote) is connected to electrically operated equipment, e.g. valves or pumps, the resistance to earth of the pipeline is decreased at these points, which can impede or prevent cathodic protection. To maintain effective cathodic protection, one of the remedies listed below may be applied (subject to relevant national or local safety regulations):

- a) isolation of the electrically operated equipment from the protected pipeline;
- b) isolation of the part of the pipeline (e.g. valve) connected to the electrical operated equipment from the rest of the pipeline by means of isolating joints, with a continuity bond between the two parts of the pipeline and separate corrosion protection for the isolated part of the pipeline (e.g. valve);
- c) installation of isolating transformers;
- d) installation of fault current circuit breaker in conjunction with a local earthing made of galvanized steel, zinc, or magnesium;
- e) installation of d.c. decoupling devices between the electrically operated equipment and the main earthing system (e.g. isolating spark gaps, surge protective device, polarization cell, electrical isolation).

7.4 Lightning and overvoltage protection

Pipelines can be affected by overvoltage and current strikes made by lightning or by nearby external power lines (e.g. earth short circuits).

To protect the isolating joint against overvoltage, an isolating spark gap should be connected across the isolating joint.

To mitigate the effect of all kinds of electrical strikes or electrical interference, isolating spark gaps, surge protective devices (SPD), or d.c. decoupling devices may also be installed between the pipeline and an earthing system, subject to national or local regulations or safety standards.

Cable length, cross section, and type have a high influence on the overvoltage protection effectiveness. They shall be matched to the isolating spark gap or SPD electrical characteristics. Cable length should be as short as possible, ensuring any loop formed on the installation is as small as possible.

NOTE To choose the type of isolating spark gaps, the following parameters are typical for cathodic protection applications for a 50 Hz case:

- d.c. spark over voltage: from 500 V to 1 kV;
- 100 % lightning impulse spark over voltage (1,2/50 μ s): $\leq 1,30$ kV for both class 1 and class 2 isolating joints, or $\leq 2,2$ kV for class 1 only (see [Annex F](#));
- nominal discharge current (8/20 μ s): 100 kA;
- lightning impulse current, I_{imp} , (10/350 μ s): 100 kA (class H), 50 kA (class N);
- rated short-duration power frequency withstand voltage (50 Hz): < 250 V;
- rated discharge current (50 Hz): ≥ 100 A / 0,5 s;

- certification according to Directive 94/9/EC “on equipment and protective systems intended for use in potentially explosive atmospheres (ATEX)”;
- proved in accordance with EN 50164-3.

7.5 Coating

7.5.1 General

Pipelines subject to cathodic protection should be installed with an external coating. The coating selection shall be approved by pipeline operator.

NOTE 1 The coating provides the primary prevention against corrosion. It reduces protection current demand, improves current distribution, extends the protected area, and reduces interference to other foreign structures.

The pipeline coating should be applied in a factory, or under factory conditions, on pipe lengths under specified conditions for surface preparation, coating application and inspection. After the welding of pipe lengths during the construction of the pipeline, girth weld areas should be coated with a compatible field joint coating.

NOTE 2 Field joints and fittings coated on site are applied under more demanding conditions and can be a weak point in the general corrosion protection system if not selected and applied correctly.

After the laying of the pipeline, coating defect surveys (see [Annex D](#)) should be carried out in order to evaluate the coating conditions.

7.5.2 Factory-applied coatings

Coatings shall be applied in accordance with

- ISO 21809-1 for polyolefin coatings (3-layer PE or 3-layer PP),
- ISO 21809-2 for fusion-bonded epoxy coatings,
- ISO 21809-4 for polyethylene coatings (2-layer PE), or
- other equivalent standards.

7.5.3 Field joint coatings

ISO 21809-3, EN 10329, or other equivalent standards should be used for the selection and application of field joint coatings.

NOTE Field joint coatings are generally either pre-shaped materials such as cold-applied tapes or heat-shrinkable sleeves or materials applied in the form of powders or liquids.

7.5.4 Coating for trenchless pipelines

Trenchless pipelines (e.g. by horizontal drilling) should be protected with external coatings with additional resistance to mechanical damage. Additional requirements for such coatings may include

- increased thickness, and
- increased mechanical resistance characteristics.

The trenchless installation should be tested for coating damage evaluation before it is tied in to the main section of the pipeline.

NOTE During trenchless installation, it is possible that some coatings will experience surface abrasion damage and this can lead to an increased level of moisture absorption. This will affect the coating electrical resistance and hence the current density requirements.

The acceptance criteria for the coating test should be determined before the installation of the pipeline.

In the absence of any specific requirement, the coating conditions can be evaluated by comparing the current density required to protect the trenchless section with the optimized design values given in [Table 3](#) (see [8.4.3](#)). Known values of current should be injected into the pipe from a temporary groundbed and the current density calculated for the section. If the current density required to achieve cathodic protection is greater than the recommended values in [Table 3](#), the trenchless pipe coating should be considered as unsatisfactory and should be remedied.

[D.4.3](#) defines an acceptable procedure for the test of the coating. Other methods can also be used.

7.5.5 Air to electrolyte interface

For an air to electrolyte interface, a high-performance coating should be used. Specific characteristics for the coating selection may include

- mechanical strength,
- UV stability, and
- adhesion.

7.5.6 Compatibility of coatings and wraps with cathodic protection

Disbondment can cause cathodic protection current shielding by preventing access of the cathodic current to the steel surface exposed to a corrosive electrolyte due to lack of continuity and/or high resistivity of the electrolyte present underneath the disbondment, renewal of corrosive species, or presence of SRB.

The selected coatings shall be compatible with the application of cathodic protection. Compatibility should be verified through cathodic disbondment tests in accordance with the applicable coating standards.

Non-bonded polyethylene wraps should be avoided as they cause shielding of the cathodic protection current and can be detrimental to the protection.

7.5.7 Thermal insulation

Thermal insulation systems are coating systems that include a layer to provide thermal insulation. This can be a dedicated layer in addition to a corrosion-protection layer or it can be a layer such as polyurethane or rubber that provides both corrosion protection and thermal insulation.

Because of the overall coating thickness and the high resistance of the different coating and insulation layers, cathodic protection is unlikely to be effective. The requirement for and the type of cathodic protection for thermally-insulated pipelines shall be evaluated considering the following.

- a) Thermally-insulating materials, such as polyurethane foam, have a high electrical resistance. Even if they become waterlogged, they are likely to shield the cathodic protection current and prevent the protection of the underlying steel pipe. Alternative corrosion control methods should be considered in such cases.
- b) The installation of a cathodic protection system solely to protect an insulated pipeline is normally difficult to justify, unless there is concern that the thermal insulation can suffer significant mechanical damage by third party action that leads to direct exposure of the pipe to the electrolyte.
- c) The intrinsically high resistance to earth of a thermally insulated pipeline precludes the discharge of any induced voltages, for example from adjacent power lines, to earth through the coating. Unless the pipeline has been directly earthed close to the point of the induced voltage, pipeline voltages can change over considerable distances, which can cause corrosion and/or become a safety hazard to personnel who make direct contact with the pipeline.

Cathodic protection potentials measured on thermally insulated pipelines are usually not indicative of the potentials at the metal-to-electrolyte interface beneath the coating. These potentials should not be used for assessing the effectiveness of the cathodic protection. Other methods should be used to verify the integrity of the pipeline at these locations.

7.5.8 Reinforced concrete weight coating

Steel reinforced concrete can be used to increase the weight of a pipeline particularly in wet areas such as marshes. Contact between the rebar of the weight coating and the pipeline shall be avoided. Isolation of the rebar from the pipeline shall be checked by measurements during application of the weight coating (in accordance with ISO 21809-5 or equivalent standard) and during pipeline operation.

7.6 Selection of pipe trench backfill material

In order to avoid the risk of coating damage or shielding effects and to achieve electrical continuity between the pipe and the electrolyte, it can be necessary to add materials to the trench such as washed sand or fine soil. Adding these materials is referred to as padding.

Imported or processed backfill is not usually necessary for coating damage protection when rock jacket coating systems are used.

7.7 Buried casings for pipelines

7.7.1 General

Casings may have a detrimental impact on the cathodic protection of the carrier pipes. Their use should be avoided where possible.

Carrier pipe within casings should have a high-quality coating for protection against corrosion.

The following measures should be implemented when the use of casings is unavoidable:

- coating of the carrier pipe;
- installation of isolating spacers in the annular space between the carrier and casings;
- sealing at the ends of the casing.

In practice, it is almost impossible to achieve a water-tight seal and a suitable filler material may be injected into the annular space. The filler material should either inhibit corrosion (e.g. visco-elastic compounds, inhibited wax) or be designed to allow cathodic protection current to reach the carrier pipe (e.g. concrete, alkaline grout).

Vent pipes shall be considered when building a casing in order to detect a leak of transported fluid. They may also be used to inject fillers for maintenance when necessary.

7.7.2 Casings that shield cathodic protection current

External corrosion protection of the carrier pipe inside sleeves which shield cathodic protection current should be achieved by

- the use of galvanic anodes provided there is an electrolyte,
- filling the annular space with appropriate material with adequate long-term corrosion protection properties,
- if galvanic anodes are used: there shall be no contact between the casing (if metallic) and the galvanic anodes, and
- consideration shall be given to the possibility of the anode corrosion products bridging the spacers.

NOTE Casings that shield cathodic protection current include plastic, coated concrete, low conductive concrete, and coated steel casings.

7.7.3 Casings that pass cathodic protection current

For casings passing cathodic protection current, the external cathodic protection of the carrier pipe can be effective in protecting the carrier pipe inside the sleeve provided there is no contact between the carrier pipe and the casing, and that there is enough electrolyte in the annular space. Without any electrolyte in the annular space, atmospheric corrosion can occur at coating defects.

NOTE Casings that pass cathodic protection current include:

- bare or poorly coated steel pipes;
- uncoated concrete pipes that are sufficiently conductive;
- well coated casings connected to a local earthing which will allow the cathodic protection current to flow.

If cathodic protection of the casing is required (e.g. because of national or local regulations), the casing should be resistively bonded to the carrier pipeline, with the resistance value adjusted to ensure that the casing is always anodic to the carrier pipeline.

7.8 Equipment for the reduction of a.c. interference

There are two basic types of a.c. interference on buried pipelines:

- short-term interference caused by a.c. high voltage power line failure and operational changes (ohmic and inductive effects; see EN 50443);
- long-term interference caused by induction during operation (inductive effect, see EN 15280 and EN 50443).

Mitigation of these effects can require the addition of earthing systems. These earthing systems may be constructed using a wide variety of electrodes (e.g. galvanized steel, zinc, magnesium) provided that these have no adverse effect on the effectiveness of the cathodic protection.

To avoid adverse effects on the cathodic protection, additional earthing systems should be connected to the pipeline via appropriate devices (e.g. d.c. decoupling devices).

7.9 Equipment for the mitigation of d.c. interference

d.c. stray currents can have an adverse impact on the effectiveness of the applied cathodic protection and can require installation of additional equipment to ensure effective external corrosion protection (see EN 50162 and EN 50122-2).

NOTE The following solutions can provide mitigation of d.c. interference:

- installation of a drainage station; drainage stations are usually connected after the commissioning of the cathodic protection system but it is prudent to install all of the equipment during construction;
- installation of isolating joint;
- improvement of the cathodic protection level in anodic d.c. stray current areas.

8 Basic requirements for cathodic protection design

8.1 General

Sizing of cathodic protection systems can be done either by calculations or on the basis of the pipeline operator experience for similar configurations.

This Clause presents guidance for the design of cathodic protection systems. The designer may use other values and formulae provided that these values and formulae are justified and the protection criteria are achieved.

8.2 Basic information for cathodic protection design

The basis for the cathodic protection design study should provide all the information necessary to carry out the detailed design. Information data may be obtained either from documents or by direct site observations and measurements.

The basis for cathodic protection design study should include the following:

- pipeline diameter;
- pipeline length and wall thickness;
- design life of the pipeline;
- pipeline coating type;
- field joint coating details;
- location of above ground installations (e.g. pressure reducing station);
- location of any valves;
- details of any local earthing (e.g. at powered valves);
- details of medium being carried;
- operating temperature of the transported medium;
- topographical details;
- elevations;
- electrolyte conditions (this may include electrolyte resistivity, pH, bacterial activity);
- results of stray current surveys in electrolyte;
- presence of high-voltage overhead power lines;
- known buried cables and structures including other pipelines;
- any known adjacent cathodic protection systems;
- river crossings;
- road and railway crossings;
- casings that will remain after construction (length, material, coating if any);
- types of pipeline bedding material;
- bridge and tunnel crossings;
- characteristics of a.c. and d.c. traction systems (e.g. sub-stations, operating voltages);
- characteristics of d.c. industrial plants;
- any electrically operated equipment (e.g. emergency shutdown valves).

8.3 Contents of cathodic protection design report

The detailed design shall address and document the following:

- a) design life of the cathodic protection system;
- b) design documents justifying the sizing and layout of equipment (e.g. anodes, transformer-rectifiers, cables);
- c) potential attenuation calculations for justification of drain point spacing if any (see [Annex E](#));
- d) materials schedule;
- e) materials specification;
- f) synoptic scheme (single line diagram) of pipeline with significant features;
- g) temporary cathodic protection systems;
- h) installation procedures and connection details for all key elements. These may include
 - 1) anode groundbeds,
 - 2) connections to anodes,
 - 3) connections to pipe,
 - 4) coating repairs,
 - 5) electrical isolation, (monobloc, insulated flanges, insulated pipes),
 - 6) Transformer-rectifiers,
 - 7) test stations,
 - 8) a.c. mitigation systems,
 - 9) sleeved crossings,
 - 10) external probes, coupons or reference electrodes,
 - 11) external electrical resistance probes,
 - 12) bonds (equipotential, resistive and unidirectional),
 - 13) drainage system, and
 - 14) remote monitoring or control;
- i) commissioning procedures;
- j) operation and maintenance instructions.

8.4 Cathodic protection current demand

8.4.1 Calculation of the theoretical total current demand

The evaluation of the current demand necessary for the cathodic protection shall be carried out from the design input data explained in [8.4.2](#) and [8.4.3](#).

As the coating status is not known at the time of design, the current cathodic protection requirement for the cathodic protection system can only be an estimation, which may be made from

- current densities for bare steel surface for coated pipelines combined with coating breakdown factors, and
- current densities for coated pipelines.

Coating breakdown factors and current densities used for the design shall be approved by the pipeline operator.

8.4.2 Current demand based on coating breakdown factors

For new pipelines, the total current demand I_{tot} , is determined using Formula (3):

$$I_{\text{tot}} = \pi D \times L \times k \times j \times f_f \quad (3)$$

where k is a contingency factor due to possible non-uniform current distribution along the pipeline, attenuation, and shielding.

NOTE Because of attenuation phenomena, the current demand along a long pipeline can be much higher. k values higher than 1,25 are normally used.

Calculation of coating breakdown factors may be done from values given in [Table 2](#). The selection of coating breakdown factors for other types of pipeline coatings shall be justified and documented.

Typical design current densities for bare steel or cast iron pipelines should be in the range of 100 mA/m² to 1 A/m², mainly depending on the oxygen diffusion rate at the metal surface and electrolyte resistivity to achieve the cathodic protection criteria.

The current demand of a coated pipeline increases with time as the coating deteriorates. Enough cathodic protection capacity should be provided to maintain protection as the coating deteriorates.

The final coating breakdown factor, f_f , is given by Formula (4):

$$f_f = f_i + (\Delta f \times t_{\text{dl}}) \quad (4)$$

where

f_i is the initial coating breakdown factor at the start of pipeline operation;

Δf is the average yearly increase in the coating breakdown factor;

t_{dl} is the design life time expressed in years.

Unless other values are justified, the coating breakdown factors in [Table 2](#) should be used provided the pipeline operating temperature does not exceed the maximum temperature for which the coating has been qualified. Coating breakdown factors should be increased to allow for damage of the coatings due to operating temperatures higher than the coating design values.

NOTE The coating breakdown factors in [Table 2](#) are based on coating quality being in accordance with the various parts of the ISO 21809 series of International Standards or equivalent.

The coating breakdown factors include some allowance for damage to pipeline coatings during fabrication, installation, and operation such as third-party damage. However, they do not include allowance for extreme damage or for field joints intentionally left uncoated. If such conditions are anticipated, the affected surface area shall be estimated and included in design calculations as bare metal surface ($f_f = 1$) or the coating breakdown factors in [Table 2](#) shall be increased.

The coating breakdown factors recommended by [Table 2](#) shall be considered for coatings fully qualified for the maximum operating temperature of the pipeline. If there is any doubt regarding the damage

and/or disbondment of the coatings with increased temperature, higher figures shall be used after documentation.

Coating breakdown factors for other types of pipeline coatings shall be fully documented.

Table 2 — Typical design coating breakdown factors

Pipeline coating	f_i	Δf
FBE	0,005	0,003
3LPE	0,001	0,000 3
3LPP	0,001	0,000 3
Liquid epoxy	0,008	0,01
Coal tar urethane	0,008	0,01

8.4.3 Current demand based on current density values for coated pipelines

An alternative method to calculate the total current demand (I_{tot}) is by calculating the total surface area of the pipeline and applying the current density for coated steel pipelines given in [Table 3](#) and using Formula (5).

$$I_{tot} = \pi D \times L \times k \times j_c \tag{5}$$

For existing pipelines without historical information, the current demand may be estimated by calculations based on assumed coating conditions. Alternatively, a test may be carried out by applying current and measuring the pipe-to-electrolyte potential at various locations along the pipeline for a known value of the applied current. The test results may be used to calculate the total current demand and groundbed spacing.

Design may also be carried out using the concept of “average coating resistance” r_{co} in ohm square metres. Correspondence between current density, j_c , and average coating resistance is possible using Ohm’s Law as given in Formula (6):

$$j_c = \Delta E / r_{co} \tag{6}$$

where ΔE is the potential shift due to cathodic protection current measured against a remote reference electrode.

Design current densities in [Table 3](#) may be used as follows.

- Values for optimized designs correspond to optimistic but realistic damage conditions and shall be used for the design of galvanic anodes or to verify the quality of a coating after pipeline installation.
- Values for conservative designs correspond to pessimistic damage conditions and should be used for the design of impressed current systems for long term operation.

Current densities for other types of pipeline coatings shall be justified and documented.

NOTE The figures for optimized design do not take into account current consumed by coupons connected to the pipeline, nor current leaving through d.c. decoupling devices, nor current from or to foreign structures. They come from experience from different operators and are included to assist the designer to size the equipment.

Table 3 — Typical design current density values for coated pipeline

Type of coating	Current density for optimized design mA/m ²	Current density for conservative design mA/m ²
3LPE or 3LPP	0,001 to 0,02	0,05 to 0,2
FBE	0,02 to 0,2	0,4 to 0,7
Coal tar or bituminous coating	0,2 to 0,3	0,3 to 0,8
NOTE These values are given for pipelines built with respect to standards mentioned in 7.5.2 and 7.5.3 .		

8.5 Cathodic protection equipment

8.5.1 Cathodic protection cables

Cables for the connection to protected pipelines, impressed current anodes, galvanic anodes, drainage stations and test stations shall be fit for buried service. Such cables should not have a metal armouring. Cables installed for use as protective earth conductors shall only be used for that purpose.

NOTE Metal armouring can cause a defect in the cable insulation if bent excessively.

Cable insulation shall be fit for the environment (for example buried, or immersed conditions and chlorine-resistant) and also for the purpose of the cable (anodic or cathodic).

Cable cross sections shall be designed on the basis of the following:

- voltage drops which are technically admissible according to the design;
- steady-state current through the cable cross section according to the design;
- cable insulation properties;
- mechanical strength;
- flexibility;
- operating temperature conditions;
- economics.

Electrical insulation of the cables of impressed current systems and for drainage systems shall not be damaged where exposed to electrolyte.

NOTE Impressed current protection can become ineffective in a very short time if its anodic cable is damaged.

Conductor material should be copper.

The total cross section of cables shall not be less than those specified below:

- a) impressed current systems:
 - 1) cable to protected pipeline 10 mm²;
 - 2) cable to groundbed 4 × 2,5 mm² or 10 mm²;
- b) galvanic anode systems:
 - 1) cable to protected pipeline 4 mm²;

- 2) cable to single anode 2,5 mm²;
- c) other installations:
 - 1) cable for potential measurement 2 × 2,5 mm² or 6 mm²;
 - 2) cable for current span measurements 4 × 2,5 mm²;
 - 3) cable for continuity bond 4 × 2,5 mm² or 10 mm².

The following requirements shall apply to cable installation:

- cables shall be laid without coils or kinks;
- separate connections shall be made between the pipeline and each core or each cable with a separate function;

EXAMPLE Cables used for potential measurement are separate from those carrying current to avoid errors due to voltage drop.

- cables should not be laid in the vicinity of power cables;
- cables shall be installed with care to avoid damage to the insulation;

NOTE 1 Sometimes it is preferable to place cables within protective sleeves or to protect cables with sufficient coverage and warning tapes, in accordance with the local appropriate electrical and safety regulations. It is also possible to bury the cables in fine-graded soil or sand.

- if any, cable routes should be marked using cable markers installed at approximately 100 m intervals and at every change of direction;
- cable joints should be avoided as far as possible. Buried and immersed cable joints should be suitable for permanent burial or immersion.

NOTE 2 The integrity of the insulation of the cable connecting the groundbed (or an element of the groundbed) to the positive pole of the impressed current station is essential. If not, moisture ingress and subsequent oxidation of the conductor can lead to the premature failure of the groundbed.

8.5.2 Cable connection

Cathodic protection cable connections to pipelines shall only be made by competent persons, in accordance with ISO 13847 or documented procedures. Documented procedures shall be approved by the pipeline operator.

NOTE Connections are typically made by

- pin brazing,
- soft-soldering,
- adhesive bonding (only for measurement cables),
- fusion-welding with metal deposit,
- stud welding,
- welding steel piece (e.g. doubler plate), directly on the pipeline, with a pre-welded stud (or equivalent system), and
- aluminothermic welding.

Welding of cable connections shall not be carried out on bends or within 200 mm of pipeline welds, fittings, and valves.

Where aluminothermic welding is used, the welding procedure shall ensure that any copper penetration into the pipeline material is less than 1 mm and that the local pipeline hardness remains within the limits of the pipe specification.

Aluminothermic welding should not be carried out on corrosion-resistant alloy pipelines.

Aluminothermic weld charges should not be greater than 15 g.

Aluminothermic welding on live pipelines shall be in accordance with a documented safety procedure addressing the following:

- inspection and/or testing requirements for the pipe wall integrity prior to welding;
- heat transfer and removal by the fluid in pipeline;
- the effect, if any, the heat of welding can have on the fluid (e.g. for certain chemicals).

Connections should be verified by mechanical and electrical tests in order to demonstrate that

- a) the surface of the protected pipeline is not adversely affected (e.g. acceptable superficial cracks on the pipeline surface), and
- b) the mechanical and electrical characteristics of the connection are suitable for the intended purpose.

Mechanical performance can be tested with a sharp blow with a 1 kg hammer; see EN 12732. Electrical performance can be tested by measuring the electrical resistance of the connection. The resistance of the connection excluding the resistance of the cable should be below 0,1 Ω .

When the testing is complete, the coating should be repaired such that future water ingress is prevented.

8.5.3 Precautions to respect for distribution boxes and test stations

All above-ground electrical equipment related to the cathodic protection of the pipeline should be suitably enclosed to protect them from unauthorized access and from the environment.

Enclosures should be located where there is safe access.

NOTE 1 The most usual above-ground equipment can be categorized as either active or passive. In this sense, active equipment includes items such as transformer-rectifiers, diode drainage bonds, and polarization cells. Passive items include items such as distribution boxes, measuring facilities, remote monitoring, and equipotential bonds. Sometimes passive measuring facilities are included with active equipment.

Active equipment should be housed in a suitably sized housing or enclosure. The size of the housing or enclosure should take into account any heat that might be generated. The material should be suitable for the anticipated environmental conditions including ultraviolet radiation. It is not necessary that the housings be lockable.

Where appropriate, the housing should have provisions for the following:

- mains power connection boxes;
- incoming electrical distribution panel with safety devices and auxiliary sockets;
- main equipment fixings (e.g. transformer-rectifier, polarization cell, diode drainage bond);
- panel for test measurements;
- earthing.

The protection category of the housing (IP) shall be selected to suit the environment and be in accordance with IEC 60529.

Each installation shall have all cables clearly marked or colour coded so that future identification is unambiguous. The housings shall have permanent identification labels.

NOTE 2 Passive equipment housings are usually much smaller than those used for the installation of electrical equipment.

Test facilities should be terminated in a suitable test station or enclosure. Easy access to the measurement terminal should be provided, and all cables should be permanently marked or colour coded to identify their purpose. If there is any risk of high a.c. voltages on the pipeline, then the measuring facility should be non-metallic (dead face) to avoid the risk of electric shock to the operator and members of the public. The test facility should have a permanent identification label.

Test facilities installed in a below grade or surface box should have mechanical strength sufficient for the anticipated traffic (e.g. surface boxes on highways or inside above ground installations).

Test facilities should be outside hazardous areas in order to avoid any risk due to sparking. If a test station is to be installed in areas classified as hazardous, it shall conform to the classification of the hazardous areas in accordance with IEC 60079-10-1 or equivalent standard.

NOTE Other documents such as API RP 500 can be used.

8.6 Temporary protection

Temporary cathodic protection should be applied during the period between trench back-filling and application of the permanent cathodic protection system to avoid the risk of pipeline external corrosion.

Temporary cathodic protection systems should be provided for the anticipated duration of the period until a permanent cathodic protection system is applied. It is prudent to apply a considerable margin of safety to allow for construction delays.

Temporary protection shall be provided if any of the following conditions apply:

- pipeline installed in low resistive electrolyte (less than 100 Ω .m);
- period between pipeline installation and permanent cathodic protection exceeds 3 months;
- pipeline installed in areas where high corrosion risks have been identified, e.g. caused by geological cells.

Depending on the electrolyte resistivities and current requirements, either zinc or magnesium anodes should be used (see [10.3](#) and [10.4](#)).

Temporary galvanic anodes shall be connected to the pipe only via above ground facilities.

NOTE Anodes directly connected to the pipe are difficult to relocate and disconnect when a permanent cathodic protection system is operational and can preclude accurate future ON/OFF CP surveys.

Anode current outputs and their effectiveness in providing cathodic protection shall be verified by measurements in accordance with [Annex A](#).

8.7 Specific case of existing pipelines

8.7.1 General

For existing pipelines, the design may be undertaken using the information from [8.4.3](#) in conjunction with field tests. Attenuation calculations may be made to determine the groundbed locations along the pipeline (see [Annex E](#)).

NOTE In some instances, the only meaningful data that can be collected are restricted to electrolyte resistivities, electrolyte analysis, stray current measurements, and the results obtained from a temporary impressed current cathodic protection system.

8.7.2 Parallel pipelines

Where pipelines are parallel, it is necessary to take precautions to ensure that there is no unacceptable interference or shielding. The interference can be the result of the influence of the applied cathodic protection, in which case the systems can need to be adjusted or the pipelines protected by a common cathodic protection system.

Where modifications to the cathodic protection or coating system are made on one pipeline, it shall have no adverse effect on the other pipeline(s).

To control current, bonds between two or more pipelines may be direct, or it can be necessary to include a diode or a series resistor installed in a test facility.

Anode groundbeds should be located with due consideration to the risk of shielding and interference.

No work should be undertaken on a parallel foreign pipeline without the consent of its operator.

NOTE 1 Bonding parallel pipelines with widely differing cathodic protection current demands will probably not be successful. In some cases separate cathodic protection systems will be required.

NOTE 2 When measuring pipe-to-electrolyte potentials on parallel pipelines that are not bonded, it is important that the reference electrode is located correctly.

8.7.3 Parallelism or crossing with a.c. power systems

Possible measures against the occurrence of critical a.c. voltage shall be studied and implemented for control of possible a.c. corrosion of the pipeline (see [Annex B](#)) and other pipeline damage.

NOTE 1 In the case of long-term a.c. influence on metallic pipelines, it is possible for a.c. to flow between bare metal (i.e. coating defect) and the electrolyte. In these conditions, a.c. corrosion of metallic pipelines can occur during normal operating conditions.

NOTE 2 a.c. corrosion risk for cathodically protected pipelines is covered in EN 15280. Other damage to the pipeline and safety for personnel are covered in EN 50443.

8.8 Trenchless installation methods

Pipelines pulled through tunnels or installed by (trenchless) horizontal drilling techniques are at risk of external coating damage caused during pulling. These construction methods preclude detailed coating inspections or close interval potential measurements once the pipeline section is installed. Other evaluation techniques should be applied to determine whether or not the coating is damaged. The evaluation techniques, see e.g. [D.4.3](#), can help to ascertain whether these pipeline sections can be cathodically protected. If the acceptance criteria after the evaluation techniques have been performed are not acceptable, then, if it is technically feasible, a coating defect survey may be carried out. This will locate where coating defects are and assist in determining any rehabilitation requirements.

The following should be provided for trenchless constructions.

- Test facilities should be installed at either side of the crossing as close as possible in order to perform the best possible measurements on the non-accessible parts of the pipeline.
- After the section has been grouted or backfilled, measurements should be made to confirm the coating integrity.
- If trenchless pipeline sections cannot be protected from the main cathodic protection system, they should be electrically isolated and separately cathodically protected.

9 Impressed current stations

9.1 General

Impressed current stations should be located where they are easily accessible and where they are protected against environmental damage, electrical damage and vandalism. The installation shall be carried out in accordance with the national and local appropriate electrical and safety regulations.

The following should be considered when selecting locations:

- proximity of an a.c. power source or possibility to use another power supply (battery, solar panel with battery);
- suitable electrolyte conditions and suitable site for the groundbed system;
- distances from the pipeline and from other metallic structures (buried structures or metallic buildings), mainly in urban areas;
- distances from other cathodic systems or a.c. or d.c. sources;
- hazardous areas.

Usually the installation work is undertaken as soon as possible after the completion of the pipeline. If required by design (see [8.5](#)), temporary cathodic protection systems should be installed and activated.

The following labels should be on the housing:

- safety signs concerning the dangers of electricity;
- identification signs concerning the owner/operator and the installation.

9.2 Power supply

The d.c. voltage source should be a transformer/rectifier unit fed by an a.c. power supply, but alternative voltage sources may be considered.

The following shall be taken into account when specifying d.c. voltage sources:

- availability and type of connection to a.c. supply;
- type of rectifier;
- measuring devices, e.g. voltmeters, ammeters;
- number of output terminals;
- type of cooling (air or oil);
- type of output control (voltage, current or potentiostatic);
- removable link to allow insertion of cyclical current interrupter;
- requirement for the permanent installation of a cyclical current interrupter;
- electrical and safety requirements for the equipment;
- protection measures against possible high voltage interference;
- requirement for a.c. and/or d.c. surge protection;
- requirement for environmental protection and housing;
- a.c. content of the d.c. output (acceptable ripple factor);

- identification and rating plate details;
- environmental protection (e.g. IP rating);
- remote monitoring / control equipment.

Generally, voltages higher than 50 V d.c. (rectifier output) should be avoided.

NOTE High voltage gradients in the electrolyte in the vicinity of groundbeds can be a hazard to animals, persons, or buildings with metallic structures.

Transformer/rectifiers shall be specifically designed for CP service and shall be suitable for continuous operation under the prevailing service conditions.

9.3 Groundbeds

9.3.1 General

The groundbeds of an impressed-current cathodic protection system shall be of the deep-well or shallow type. The design and location shall meet the following.

- a) Quantity of the groundbed materials (anode and backfill) shall be compatible with the groundbed size and design life of the cathodic protection system.
- b) The resistance to remote earth of each groundbed shall allow the maximum predicted current demand to be met at no more than a value defined during the design (e.g. 70 % of the voltage capacity of the d.c. source) during all seasons of the year and throughout the design life of the cathodic protection system. Calculation shall be based on the resistance of the anode groundbed at the end of its design life.

NOTE Formulas to calculate the resistance are given in NACE Corrosion Engineer's Reference Book (3rd Edition).^[4]

- c) Harmful interference on neighbouring buried structures, including fences, foreign pipelines, facility piping, and earthing systems, shall be avoided.

In selecting the location and type of groundbeds for installation, the following local conditions shall be taken into account:

- electrolyte conditions and the variation in resistivity with depth;
- groundwater levels;
- any evidence of extreme changes in electrolyte conditions from season to season;
- nature of the terrain;
- shielding (especially for parallel pipelines);
- likelihood of damage due to third-party intervention.

The basic design shall include a calculation of the groundbed resistance based upon the most accurate electrolyte resistivity data available.

If multiple groundbeds are necessary to deliver the current demand, then the current output from each groundbed should be independently adjustable.

9.3.2 Deep-well groundbeds

Deep well groundbeds should satisfy the NACE SP0572.

Deep-well groundbeds should be considered where

- hydrologic and geoelectric underground conditions allow them,
- electrolyte conditions at depth are far more suitable than at surface,
- there is a risk of shielding by adjacent pipelines or other buried structures,
- available space for a shallow groundbed is limited, and
- there is a risk of interference currents being generated on adjacent installations.

The detailed design shall include a procedure for drilling the deep well, establishing the resistivity of the electrolyte at various depths, completing the borehole and method of installing the anodes and conductive backfill.

The borehole design and construction shall be such that the undesirable transfer of water between different geological formations and the pollution of underlying strata is prevented. In some countries, this activity may require special tests and documentations.

Where necessary, metallic casings should be used for stabilizing the borehole in the active section of the groundbed. The metallic casing shall be electrically isolated from any structures on the surface.

NOTE Metallic casings provide only temporary borehole stabilization, as the metal will be consumed by the d.c. current flow.

If permanent stabilization is required, non-metallic, perforated casings should be used. In the calculation of the groundbed resistance, the electrolyte resistivity data corresponding to the depth at the midpoint of the active length shall be used and the possibility of multi-layered electrolytes with significantly different electrolyte resistivities considered.

Deep-well groundbeds should be provided with adequate vent pipes to prevent gas blocking between anodes and the conductive backfill. Vent pipe material shall be manufactured from a non-metallic chlorine-resistant material.

9.3.3 Shallow groundbeds

Shallow groundbeds should be considered where

- electrolyte resistivity near the surface is far more suitable than at the depths of a deep-well groundbed,
- there is no risk of shielding by adjacent pipelines or other buried structures,
- space is available for a shallow groundbed, and
- the current being generated does not create unacceptable corrosion on adjacent buried structures.

Shallow groundbed anodes shall be installed horizontally or vertically. In either case, the top of the conductive backfill shall be at least 0,8 m below ground level or at least below permafrost level (when applicable). In the calculation of the groundbed resistance, the electrolyte resistivity data corresponding to the centre-line (horizontal groundbed) or mid-point (vertical groundbed) of the anodes shall be used and the possibility of multi-layered electrolytes with significantly different electrolyte resistivities shall be considered.

The detailed design shall include a procedure for the construction of the groundbed, for the installation of the anodes and for the conductive backfill.

Permanent marking should be considered for the beginning and the end of each groundbed.

9.3.4 Impressed-current anodes and conductive backfill

Anode materials should be selected from the following list:

- high-silicon iron alloy, with appropriate chromium concentrations if used in electrolytes with high chloride content and if allowed by regulations;
- magnetite;
- graphite;
- mixed-metal-oxide-coated titanium;
- conductive polymers;
- steel.

Alternative materials may be used if reliable performance for the specific operating conditions can be demonstrated and is documented.

Dimensions and mass of the selected material shall be capable of delivering 125 % of the required anode current output throughout the design life of the cathodic protection system.

Backfill material shall be used to decrease anode-to-electrolyte resistance unless the electrolyte conditions give a satisfactory grounded resistance, the electrolyte is homogeneous and a uniform consumption of anodes is expected.

Electronic conduction backfills are generally used with impressed current anodes because they allow:

- a reduction of the anode consumption;
- an improvement in the gas percolation.

NOTE Backfill material can have either an electronic conduction (e.g. coke, graphite and magnetite) or an electrolytic conduction (e.g. bentonite and gypsum).

Care should be taken with electrolyte backfills to prevent the drying out of the backfill during operation of the impressed current system.

The environmental impact of the dissolution of anode materials and breakdown of the conductive backfill material shall be considered.

The backfill should be checked to verify whether it is suitable and has been correctly prepared. It is particularly important to check that the backfill is both sufficient in quantity and homogeneous, and meets the requirements of the project specification.

Use of continuous conductive polymer anodes or titanium MMO wire should be considered, particularly for very high resistivity electrolytes surrounding the pipeline.

Anode performance should be verified with the manufacturer. Typical electrochemical characteristics of anodes used for impressed current systems of buried pipelines are given in [Table 4](#). In case when carbonaceous backfill is used, the coke consumption should be taken into account in the grounded sizing.

Table 4 — Typical electrochemical characteristics of impressed current anodes in soil

Anode materials	Consumption rate $\text{g}\cdot\text{A}^{-1}\cdot\text{y}^{-1}$	Typical range for anodic current density $\text{A}\cdot\text{m}^{-2}$
Scrap steel	10 000 to 12 000	1 to 5
High silicon iron alloy	250 to 1 000	10 to 30 ^b
Impregnated graphite	500 to 1 000	2,5 to 10 ^b
Magnetite	2	10 to 20 ^b
Mixed metal oxide (MMO) on titanium substrate in carbonaceous backfill	a, c	50 to 100 ^b
Conductive polymers in carbonaceous backfill	a	0,4 ^b

NOTE When impressed current anodes are installed with carbonaceous backfill, it is necessary to take into account the consumption rate of carbonaceous backfill. Typically, it is $900 \text{ g}\cdot\text{A}^{-1}\cdot\text{y}^{-1}$ to $2\,000 \text{ g}\cdot\text{A}^{-1}\cdot\text{y}^{-1}$ and a typical range for anodic current density is $5 \text{ A}\cdot\text{m}^{-2}$.

^a These anodes are usually installed in a carbonaceous backfill. The design life is generally governed by the carbonaceous backfill consumption rate. The consumption rate of the anode is therefore insignificant.

^b The anode manufacturer's maximum current density recommendations should be observed.

^c NACE/TM 0108-2008[2] gives recommendations for testing catalysed titanium anodes in soil.

9.4 Output control

9.4.1 General

The output current from a rectifier may be controlled by the following:

- constant output rectifier voltage: the current is controlled by the circuit resistance. Changes in the external circuit (e.g. stray currents, electrolyte variations) will result in changes of the value of applied current to the pipeline;
- potential control: the potential measured on the pipeline at a representative location and fed back to the rectifier, which adjusts the transformer rectifier output and maintain the preset potential measures on the pipeline. Changes in the external circuit (e.g. stray currents, electrolyte variations) will result in changes of the value of applied current to the pipeline;
- current control: the current delivered by a rectifier is automatically controlled by comparison to a set value.

The electrical circuit between the groundbed and the pipeline, through the transformer rectifier, should be left open at the transformer rectifier until commissioning.

9.4.2 Current distribution for multiple pipelines

When more than one pipeline is being cathodically protected by one rectifier, the parameters below shall be considered:

- pipeline routes;
- pipeline owner/operator;
- electrical influence;
- current demand for each pipeline;
- cathodic protection shielding effect (position of the groundbed versus different pipelines).

Resistors should be installed in the negative drains to balance the current to each of the adjacent pipelines individually. Each negative drain may be provided with a shunt and diode preventing mutual influence of pipelines during ON-potential and OFF-potential measurements (see [Annex A](#)).

All cables, diodes, and current measurement facilities should be installed in a distribution box or transformer-rectifier cabinet.

Cathodic protection on multiple pipelines from a single transformer rectifier may be achieved by the use of equipotential bonding if cathodic protection effectiveness is achieved. This, however, limits the possibility of measuring the potentials of individual pipes.

9.4.3 Potential control

The d.c. voltage source can be required to maintain a constant pipeline potential to compensate for changes in the external circuit conditions. Changes can be caused by stray or telluric current interference.

In such cases, the voltage measured by a permanent reference electrode may be used as a controlling potential to change the transformer-rectifier output to maintain a constant pipe to electrolyte potential. The reference electrode shall be placed so that it accurately reflects the potentials that are necessary to control (e.g. close to the pipeline).

NOTE The control of the output characteristics is usually done electronically, which has the benefit that the current output can be limited to prevent over protection in the event of reference electrode failure.

Permanent reference electrodes shall be regularly monitored.

The potential measuring circuit used to provide the control shall have a minimum input resistance of 10 M Ω . The electronic control system shall have a resolution of at least ± 10 mV and be provided with controls to set the required protection potential and the current limit and/or visual alarms for over voltage or over current situations.

Panel meters shall be provided to show the output voltage, output current, and protection potential.

10 Galvanic anode systems

10.1 General

Galvanic-anode systems should be considered when the current demand is low. They are more adapted for small-diameter pipelines, short lengths (a few kilometres) of coated larger diameter pipelines, and in low resistivity electrolytes (where the anode is installed), water, swamps, or marshes.

Application of galvanic anodes may also be considered

- if no power for impressed current is available,
- for temporary protection of newly laid pipelines,
- for temporary protection of existing pipelines,
- if maintenance of the electrical equipment associated with an impressed current is impractical,
- for localized (hot-spot) protection to supplement impressed-current systems (e.g. in the case of a complex structure or anodic areas such as next to an isolating joint),
- where remote groundbeds for impressed-current systems cannot be provided,
- in the thaw-bulb at locations where the electrolyte around the pipeline can freeze (permafrost),
- under thermal insulation where external impressed current system cannot be effective due to the electrical isolation supplied by the thermal coating, and

- when a shielding effect can prevent the cathodic protection current from reaching the pipeline.

10.2 Design requirements

For a successful cathodic protection of pipelines, the design of galvanic-anode systems shall meet the following requirements:

- the chosen anode material shall deliver the required protection current (taking into account the resistivity of the electrolyte and the driving potential of the anode) along the pipeline;
- the anode shall be capable of continuously supplying the maximum current demand;
- the mass of the anode material shall be sufficient to supply the required current for the design life of the pipeline system.

Galvanic anodes should be marked with the type of material (e.g. trade name, anode mass without anode backfill, and cast number). Full documentation of number, types, mass, dimensions, chemical analysis, and performance data of the anodes shall be provided.

The environmental impact of galvanic anodes and their backfill shall be considered.

NOTE For buried pipeline applications, the two main anode materials used are zinc and magnesium alloys (see EN 12496). Specific practical data concerning the properties of these materials are given in [10.3](#) and [10.4](#).

Aluminium anodes shall not be used in buried conditions in electrolyte except where the chloride content of the electrolyte is high enough.

Other alloys may be used providing the reliability of their performance in electrolytes is demonstrated.

The calculation for determining the anode mass shall take into account a utilization factor, u , corresponding to the shape deterioration of the anode with time. Except when otherwise specified, a value of 0,80 should be used for this factor.

10.3 Zinc anodes

Typical compositions of zinc anodes are given in [Table 5](#) (see EN 12496). [Table 6](#) gives typical electrochemical characteristics common to the three type of alloys in [Table 5](#). When installed in soil for pipeline applications, zinc anodes shall be used with anode backfill, except when soil contains chlorides or sulphates.

NOTE In environments where carbonates, bicarbonates, or nitrates dominate, the potential of the zinc becomes very noble due to the presence of passivating surface films. This effect can reduce the zinc anode efficiency. This phenomena doesn't appear if the electrolyte contains sulphates or chlorides.

Table 5 — Typical chemical compositions of the alloys used for zinc anodes

Elements	Alloy Z 1 ^a mass %	Alloy Z 2 ^b mass %	Alloy Z 3 mass %
Al	0,1 to 0,5	0,005 max	0,10 to 0,20
Cd	0,025 to 0,07	0,003 max	0,04 to 0,06
Fe	0,005 max	0,001 4 max	0,001 4 max
Cu	0,005 max	0,002 max	0,005 max
Pb	0,006 max	0,003 max	0,006 max
Sn	—	—	0,01 max
Mg	—	—	0,5 max
Others	0,10 max	0,005 max	0,1 max
Zn	99,314 min	99,99 min	remainder

^a Alloys Z1 is normally supplied in accordance with US. MIL-A-18001-K-93[Z] or to ASTM B418-12,[5] Type I.

^b Alloy Z2 is often termed “high purity zinc” and is normally supplied in accordance with ASTM B418-12[X], Type II.

Table 6 — Typical electrochemical parameters for zinc anodes used in soils

Parameter	Zinc anode
Open circuit potential (V versus saturated Cu/CuSO ₄)	-1,05 to -1,10
Closed circuit potential (V versus saturated Cu/CuSO ₄)	-1,00 to -1,05
Practical electrochemical capacity (A·hr/kg)	780
Practical consumption rate (kg/A·yr)	11,2

Zinc anodes, even with backfill, should not be used if the resistivity of the soil is higher than 50 Ω.m, unless the engineering evaluation or field test confirms that the design requirements can be met.

10.4 Magnesium anodes

Typical compositions of magnesium anodes in accordance with EN 12496 are given in [Table 7](#). [Table 8](#) gives typical electrochemical characteristics. When installed in soil for pipeline applications, magnesium anodes should be used with anode backfill.

Table 7 — Typical chemical compositions of the alloys used for magnesium anodes

Elements	Alloy M 1 ^a mass %	Alloy M 2 mass %
Mn	0,25 min	0,5 to 1,5
Al	5 to 7	0,05 max
Zn	2 to 4	0,03 max
Fe	0,005 max	0,03 max
Cu	0,08 max	0,02 max
Si	0,3 max	0,05 max
Pb	0,03 max	0,01 max
Ni	0,003 max	0,002 max
Others total	0,30 max	0,30 max
Mg	remainder	remainder

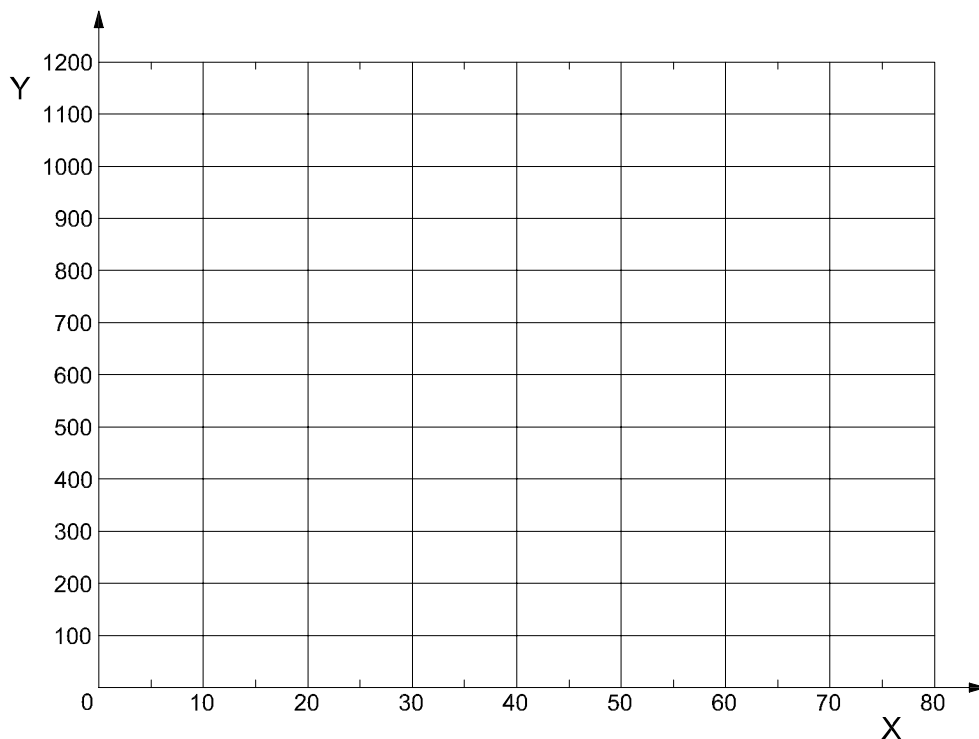
^a Alloy M 1 is normally supplied in accordance with ASTM B843-09.[\[6\]](#)

Table 8 — Typical electrochemical parameters for magnesium anodes used in soils

Parameter	Alloy M 1 mass %	Alloy M 2 mass %
Open circuit potential (V vs. sat. Cu/CuSO ₄)	-1,57 to -1,60	-1,77 to -1,82
Closed circuit potential (V vs. sat. Cu/CuSO ₄)	-1,52 to -1,57	-1,64 to -1,69
Practical electrochemical capacity (A·h/kg)	1 100	1 100
Practical consumption rate (kg/A·y)	7,5	7,5

Magnesium anode, even with backfill, should not be used if the resistivity of the soil is higher than 100 Ω·m unless the engineering evaluation or field tests confirm that the design requirements can be met.

NOTE Current efficiency is reduced if the anode current density is lower than 200 mA/m² (see [Figure 1](#) for magnesium alloy M 1).

**Key**X current density ($\mu\text{a}/\text{cm}^2$)Y current capacity ($\text{A}\cdot\text{h}/\text{kg}$)

NOTE [Figure 1](#) comes from R.A. Gummow, "Performance efficiency of high potential magnesium anodes for cathodically protection iron watermains", Proceedings of North Area Eastern Conference).^[8]

Figure 1 — Current capacity of magnesium alloy M 1 versus current density

10.5 Design of the anode system

For pipeline applications, anodes are often manufactured in rod elements with circular or rectangular cross-section.

Several anodes can be electrically connected to the pipe at the same location to deliver the total current. However, particularly for long sections of pipes or in non-homogeneous electrolytes, the anodes may be spread out along the pipeline for a better distribution of the protection current.

The total net anode mass, m , required to maintain protection throughout the design life shall be calculated for each section of pipeline in accordance with Formula (7):

$$m = I_{\text{cm}} \times t_{\text{dl}} \times \frac{8760}{u \times \varepsilon} \quad (7)$$

where

I_{cm} is the mean current demand, in ampere;

t_{dl} is the design life, in years;

ε is the electrochemical capacity of the anode material, ampere hour per kilogram.

The number of anodes, their dimensions, and net mass shall be determined in order to meet the estimated final current requirements for protection of the pipeline section using Formulae (8) to (12) given below.

The number of anodes, n , is given by Formula (8):

$$m = n \times m_a \quad (8)$$

where

m is the total net anode mass, in kilogram;

m_a is the individual net anode mass, in kilogram.

The required end-of-life individual anode current output, I_f , shall be calculated from Formula (9):

$$I_f = \frac{I_{cf}}{n} \quad (9)$$

where

I_{cf} is the total current demand for the cathodic protection of a specific pipeline section at the end of life (for maximum coating breakdown factor), in ampere.

For given anode dimensions, the actual individual end-of-life anode current output, I_{af} , shall be calculated from Formula (10):

$$I_{af} = \frac{E_c - E_a}{R_a} \quad (10)$$

where

E_a is the design closed-circuit potential of a galvanic anode, in volts;

E_c is the design protection potential (minimum negative potential), in volts;

R_a is the total circuit resistance for a galvanic anode cathodic protection system (assumed to be equivalent to the anode resistance), in ohm

NOTE $E_c - E_a$ is generally referred to as the design driving voltage.

To provide end-of-life protection, the actual end-of-life anode current output shall be greater than or equal to the required end-of-life current output as given in Formula (11):

$$I_{af} \geq I_f \quad (11)$$

The overall anode resistance R_a shall be calculated. In this aim, the anode resistance, $R_{a/b}$, relative to the backfill, and the backfill bed resistance, $R_{b/s}$, relative to the natural electrolyte can be calculated using Dwight's formula (see Reference [4]).

For the end-of-design-life anode resistance, anodes shall be assumed to be consumed to the extent indicated by the utilization factor. The approximate end-of-design-life anode dimensions should be used in the anode resistance equation for R_a .

The overall anode resistance R_a is then given by Formula (12):

$$R_a = R_{a/b} + R_{b/s} \quad (12)$$

10.6 Anode backfill

For galvanic anodes, only electrolytic conduction backfills shall be used. They should consist of a mixture of gypsum, bentonite clay and sodium sulfate.

The required composition of the anode backfill material shall be included in the anode specification.

The composition of backfill shall be determined such that the local resistivity is lowered and the build-up of insulating corrosion products around the anode surface is prevented.

Backfill for zinc and magnesium anodes may consist of a 20 % mud of bentonitic clay for water retention, 75 % gypsum and 5 % of sodium sulfate to improve the local conductivity around the anodes.

NOTE Gypsum helps to minimize the anodic polarization of the anode, mainly for zinc anodes.

10.7 Cables and cable connections

The connection between galvanic anode cables and the pipeline shall be in an accessible facility. This allows carrying out potential and current measurements. Permanent high resistance measuring shunts in the anode circuit should not be installed to prevent reduction of current.

10.8 Anode installation

The anodes should be buried at 3 m to 5 m from the pipeline and at pipeline depth or lower to reach a wet electrolyte with better resistivity.

The galvanic anodes should not be buried directly in the electrolyte but in a backfill.

Anodes directly packaged in a porous sack bag filled with a dry backfill shall be immersed in a muddy mixture of soil and water to dampen the backfill before burial.

11 Monitoring facilities

11.1 General

Monitoring facilities shall be installed along the pipeline route to allow measurement of the performance of the cathodic protection.

11.2 Locations of test stations

To monitor pipe-to-electrolyte potentials, currents and possible interferences, test stations should be installed along the pipeline at intervals not greater than

- 3 km in rural areas, and
- 1 km in urban or industrial areas.

Test stations shall also be installed at special features, such as the following:

- isolating joints;
- connections to earthing systems;
- metallic casings;
- bond connections to other pipelines or facilities;
- connections with coupons and grounding;
- impressed current stations;
- drainage stations.

Test stations should also be installed where the pipeline

- crosses or runs parallel with a.c./d.c. traction systems;
- crosses or runs parallel with a.c. power lines;

- crosses or runs parallel with other pipelines;
- crosses major roads and embankments (such as dykes);
- crosses railways and rivers;
- crosses highly aggressive soil conditions (e.g. polluted areas, very low soil resistivity, ...);
- can be influenced by shielding effects;
- runs close to other structures with a cathodic protection system;
- runs through non-metallic casings;
- is used as a shunt to carry out line current measurements.

Generally, the test stations should be installed above the pipeline. Test stations should be identified.

NOTE In urban and industrial areas, it can be necessary to install additional facilities to provide contact with the soil for reference electrode at the measuring point.

For the verification of the integrity of the connections, two separate conductors can be attached to the pipeline with two different connections. All conductors in the same test station shall be identified by colour-coding or tags.

11.3 Description of test stations

Test stations may contain the following:

- one or several cables connected to the pipeline;
- one or several cables connected to specific devices such as permanent reference electrodes, coupons, probes, ER probes, and d.c. decoupling devices;
- one or several cables connected to neighbouring structures;
- one or several cables connected to casings;
- two or more cables connected to the pipeline for line current measurements.

11.4 Use of probes and coupons

Coupons or probes should be used when required (see [Annex A](#)) to

- eliminate IR drops when conventional ON-OFF potential measurements cannot be carried out, e.g. in presence of d.c. stray currents, equalizing currents and electrical interferences from cathodic protection systems of neighbouring structures,
- evaluate a.c. corrosion risks (see EN 15280),
- evaluate d.c. and /or a.c. current densities, and
- evaluate corrosion rates of steel in the electrolyte (ER probe).

Coupons or probes should be installed as close as possible to the pipeline to represent the pipeline operating conditions. This might not be possible always such as close to pipelines operating at high temperature (e.g. for ER probes) or in urban areas.

NOTE Probes provide more accurate measurements when compared with coupons for assessing the cathodic protection effectiveness. In this case, a permanent reference electrode is normally installed close to a coupon in order to minimize IR drops. The accuracy of the measurement is improved if the reference electrode is regularly calibrated.

11.5 Bonding to other pipelines

Where a bonding facility at crossings with other pipelines is required, this should consist of two separate, suitably sized, conductors attached to each individual pipeline, terminating in a test station with facilities to install direct, unidirectional, or resistive bonds as required.

11.6 Test facilities at cased crossings

To detect contacts between a metallic bare casing and the carrier pipe and to assess the cathodic protection effectiveness, one conductor shall be installed on the pipeline and another one on the casing. To localize a contact between a metallic bare casing and the carrier pipe, two test conductors should be installed on both ends of the casing and two test cables should be installed on the pipeline at both ends of the casing. All cables shall be terminated in test stations.

11.7 Test facilities at isolating joints

Connections to the pipeline shall be installed on each side of all isolating joints to check their functionality. If conductors are installed, they should arrive at the same test station and be correctly sized to install direct, unidirectional or resistive bonds, and surge protective devices.

11.8 Line current monitoring test stations

For line current measurements, each cable connection to the pipeline shall be identified to ensure that the direction of current flows can be established. Cable configuration, installation, and calibration shall be in accordance with [Annex A](#).

11.9 Drain-point test facilities

At drain points, each negative connection to the pipeline should be provided with current measurement facilities, normally installed at the d.c. power source. Where multiple negative connections are installed, separate shunts and, where necessary, blocking diodes should be provided.

At drain points, a test station should be installed using a separate test conductor from the current drain conductor. This conductor, connected to the pipeline, shall be dedicated to the measurement of the drain point potential. A test station is not required if the drain point is installed on an above-ground section of the pipeline.

11.10 Miscellaneous monitoring facilities

Where pipelines run through remote areas or access on a regular basis is difficult, remote monitoring using long-distance cables, telemetry or other data transmission systems in conjunction with permanent reference electrodes and coupons should be used.

12 Commissioning

12.1 General

Commissioning of cathodic protection systems shall be in three steps as follows:

- preliminary test to verify that the cathodic protection system is installed in accordance with the design requirements;
- start-up of the cathodic protection system;
- verification of the cathodic protection effectiveness in accordance with the criteria defined in [Clause 6](#) and to adjust if necessary.

These three steps are necessary to confirm a fully functional cathodic protection system and to provide reference information for future controls.

The commissioning work shall be documented with the final report containing the results of measurements, changes made to the design and all information which can be useful for future monitoring.

Measurements should be carried out while the interference source is under normal and representative operating conditions.

12.2 Preliminary tests

All electrical installations should be constructed and verified by electrical personnel approved in accordance with local regulations. All necessary safety documents shall be available before commencement of the preliminary tests.

Compliance of the cathodic protection system with the design shall be confirmed before activation. Deviations shall be corrected or reviewed for acceptance before start up.

All temporary cathodic protection systems shall be disabled and the pipeline depolarized before commencement of preliminary testing. Prior to energizing the cathodic protection system, the following checks should be performed to confirm:

- a) electrical integrity of the cathodic protection circuit (e.g. anode and cathode junction boxes, foreign structures);
- b) transformer-rectifier stations:
 - tightness of screws and nuts;
 - accessories are securely mounted;
 - correct denomination of pipeline and groundbed cables;
 - correct output polarity of the transformer rectifier;
- c) oil-cooled transformer-rectifiers:
 - required oil level;
- d) electrical drainage stations:
 - tightness of screws and nuts;
 - accessories are securely mounted;
 - correct polarity of pipeline and rail cables;
 - on pipeline potential for at least 24 h for later comparison;
- e) functioning of isolating joints, for which methods described in [Annex A](#) or others if justified may be used;
- f) electrical isolation of earthing devices and metallic casings;
- g) resistance measurements:
 - resistance against remote earth of the groundbed or the galvanic anode;
 - resistance between the pipeline to be protected and the groundbed;
- h) test stations:
 - correct marking of cables and terminals;
 - tightness of cable terminations;

- i) correct installation of coupons and working electrodes;
- j) potential measurements at measuring points:
 - corrosion potential, E_{COR} , of the pipeline on all test stations;
 - influence on the pipeline from a.c. or d.c. sources;
 - anode to electrolyte potential of galvanic anodes;
 - structure to electrolyte potential of neighbouring foreign structures.

The information from these checks shall be provided to the personnel responsible for the start-up, verification of the effectiveness, and drafting of the commissioning report.

12.3 Start up

12.3.1 Impressed current stations

The start-up phase shall include the following steps:

- switch on the impressed current stations and confirm that it is functioning correctly;
- adjust station settings to conform the potential requirements of the design. The causes of major deviations should be ascertained by measurements.

Immediate action shall be taken if the pipeline potential moves towards more electropositive values after energizing the d.c. current sources.

The following measurements shall be performed on all impressed current stations:

- rectifier output voltage on impressed current stations;
- protection current outputs;
- ON-potential at drain points.

Depending on the evaluation of the results of these measurements, the setting parameters should be adjusted and measurements carried out again.

NOTE [Annex C](#) describes some typical troubleshooting information.

12.3.2 Galvanic anodes

The start-up phase shall include the following steps:

- after connecting all galvanic anodes as defined in the cathodic protection design, it shall be confirmed that they are functioning correctly. If major deviations occur, the causes should be ascertained by measurements and corrected;
- when necessary, connection of galvanic anodes may be carried out via variable resistors for current limitation.

The following measurements shall be performed on all galvanic anodes:

- protective current output of each galvanic anode;
- ON-potential of the pipeline at galvanic anodes locations.

If the evaluation of the results of these measurements suggests any doubt for the effectiveness of the cathodic protection, then the setting parameters of the resistors, if any, should be adjusted and measurements carried out again.

12.3.3 Drainage stations

After confirmation that the drainage is functioning correctly, the following measurements shall be performed and recorded:

- drainage current for at least 24 h;
- correct functioning of the unidirectional device (diode);
- ON-potential of the pipeline and potential of other foreign structures, such as railways, at the drainage station sites with the drainage connected for at least 24 h and not connected for at least 24 h;
- direction and magnitude of currents on coupons, if any, for at least 24 h.

12.3.4 Test stations

The following measurements shall be performed at test stations:

- ON-potential at the extremities of the protected pipeline;
- ON-potential at critical locations;
- ON-potential and current on coupons, if any;
- structure of electrolyte potentials of neighbouring foreign structures to verify any possible influence on them;
- ON-potential and current through the bond at bonded structures;
- ON-potentials to verify the electrical isolation of the pipeline at isolating joints, metal casings, reinforced concrete, earthing systems.

12.4 Verification of cathodic protection effectiveness

12.4.1 General

The pipeline to electrolyte potentials shall be measured once the pipeline to protect has sufficient contact with the electrolytic medium consecutive to trench backfill consolidation, is operating at its design condition (temperature, pressure) and after a suitable polarization period (principally depending on the nature of the electrolyte and the protection current density through the coating defects).

The pipeline to electrolyte potentials shall meet the criteria in [Clause 6](#).

12.4.2 Measurements of d.c. potential and a.c. voltage

The following measurements shall be carried out:

- d.c.ON-potentials and a.c.voltages at each test station: In areas where the measured potentials or voltage drops fluctuate (e.g. as a result of interference from a d.c. traction system), measurements should be made using a data logger, preferably during 24 h, and simultaneously with adjacent test stations;
- OFF-potentials without d.c. stray currents at all selected test stations as defined in [13.3](#);

NOTE It is preferable to carry out these measurements at all test stations.

- with d.c. stray currents, OFF-potential measurements on external potential test probes or coupons at all equipped test stations and preferably recorded over 24 h.

12.4.3 Current measurements

The following measurements shall be carried out:

- d.c. protective current at each impressed current station, including the measurement of current in each negative cable;
- d.c. protective current at each galvanic anode;
- d.c. and a.c. currents flowing through bonds with the direction of d.c. currents, particularly in the presence of d.c. railways stray currents;
- d.c. current at d.c. drainage station, preferably recorded over 24 h;
- d.c. and a.c. currents through d.c. decoupling devices;
- d.c. and/or a.c. currents through external test probe or coupon, preferably recorded over 24 h in case of d.c. stray currents and/or a.c. interferences.

12.4.4 Adjustments

If the effectiveness of the cathodic protection system is not reached, adjustments of the cathodic protection system shall be made and measurements repeated until the cathodic protection of the entire pipeline in accordance with the design is achieved.

NOTE Possible adjustments are the following:

- adjustment of the protection current (increase or decrease);
- installation of new drainage station if necessary;
- adjustment of the circuit resistance of the drainage device (increase or decrease), if any;
- installation of d.c. decoupling devices;
- installation or disconnection of bonds.

12.5 Commissioning report

12.5.1 Installation documentation

As-built documentation shall be prepared containing as a minimum the following:

- design documentation (see [14.1](#));
- protection criteria applied in accordance with [Table 1](#);
- description and specifications of all the cathodic protection equipment used (such as impressed current source, galvanic anode, drainage, remote monitoring system, and groundbeds);
- as-built installation drawings of the pipeline, its cathodic protection system and adjacent structures;
- schematic diagram showing all a.c. and d.c. connections;
- recommended monitoring and maintenance programmes including frequencies.

12.5.2 Commissioning measurements

All the data collected during the commissioning shall be gathered in a commissioning report, which should include the following:

- impressed current source settings (output voltage, current delivered, type of regulation, etc.);

ISO 15589-1:2015(E)

- galvanic anode measurements (potential and current);
- grounded or galvanic anode resistance values;
- pipeline to soil potentials (ON and OFF);
- a.c. voltage on the pipeline;
- coupon potentials (ON and OFF);
- current measured on coupons;
- current from bonds;
- current from drainage bonds;
- values of resistors used on the cathodic protection system;
- isolation device verification measurements (e.g. potentials, resistance);
- interference test results carried out before and after commissioning;
- evaluation of cathodic protection effectiveness at the time of completion of the commissioning;
- description and results of any corrective actions taken during commissioning;
- description of any foreseen corrective actions that do not have any impact on the cathodic protection effectiveness.

NOTE 1 This commissioning report attests that the measured values are consistent with the protective criteria and that the effectiveness of cathodic protection of the pipeline is reached at this time.

NOTE 2 The commissioning report records the reference values for comparison with future measurements during monitoring and inspection operations of cathodic protection of the pipeline.

13 Monitoring, inspection, and maintenance

13.1 General

Inspection and monitoring of the cathodic protection system shall be carried out at regular intervals (see [13.3](#)) to confirm that the protection criteria are fulfilled and to detect any deficiencies. The criteria may not be achieved at locations where the protection is deficient due to shielding effects or unusual contaminants in the electrolyte.

Inspection and monitoring shall be carried out according to appropriate procedures.

Measurements and findings of the monitoring and inspection activities shall be analysed to

- review the adequacy of the corrosion management,
- identify possible deficiencies and carry out improvements,
- indicate the necessity for a more detailed assessment of the pipeline condition, and
- determine the requirement for the measurement of a.c. interference.

The following factors shall be considered when determining the inspection frequencies and requirement for special investigations:

- corrosive nature of the external electrolyte (soil or water);
- susceptibility of pipeline to mechanical damage;

- d.c. or a.c. interference;
- susceptibility of cathodic protection installations to damage by lightning, over-voltage, or mechanical means;
- risks associated with the consequence of a failure of the pipeline;
- material, extent, and complexity of the pipeline;
- constructional features critical to maintaining effective cathodic protection (e.g. casings on pipelines);
- quality of applied protective coating;
- use of remote monitoring;
- use of galvanic anodes or impressed current stations;
- type of power supply (such as solar panel or thermo electric generator);
- use of unidirectional drainages;
- safety and environmental concerns;
- age and history of the pipeline;
- regulatory requirements.

13.2 Implementation of inspection

In general, the effectiveness of cathodic protection is assessed by comparing actual measurement values with reference values or protection criteria. Measured values established at cathodic protection stations and test points at the time of commissioning as well as in subsequent years shall be used as reference values.

If there are indications that cathodic protection is not fully effective throughout the pipeline, investigations should be carried out and appropriate corrective action taken to restore the effectiveness of cathodic protection. The measured values established from this investigation shall then be used as the new reference values.

13.3 Periodicities of inspection

Minimum requirements for routine measurements and equipment checks shall be in accordance with [Table 9](#).

All measurements and checks shall be recorded.

The effectiveness of the cathodic protection shall be demonstrated in two steps:

- a) for general assessment of the effectiveness of cathodic protection, ON-potential measurement should be used, and carried out in accordance with [Table 9](#). These measurements shall be carried out at all or at selected test stations. Selected test stations may be those at the limits of the pipeline, e.g. at isolating joints, test stations where the least negative potentials were measured during commissioning, at critical points or those shown to be representative of the cathodic protection system. Test stations associated with foreign structures should be included, so that any changes can be detected;
- b) for detailed and comprehensive assessment of the effectiveness of cathodic protection, measurement methods shall be appropriate for the pipeline and as follows:
 - measurement methods may be OFF-potentials carried out in accordance with [Table 9](#) and preferably at all test stations;
 - when OFF pipe-to-soil potential is impossible to be carried out, OFF-potential measurements over a sufficient period of time on external test probes or coupons are required in accordance with [Table 9](#);

- detailed investigations to prove the effectiveness of cathodic protection should also be carried out in the following circumstances:
 - if any damage to the protective coating or metallic contact is suspected after construction work in the area of the coated pipeline;
 - in the event of any indications of pipeline movement (e.g. in areas of subsidence or changes in operating conditions);
 - any other changes to the pipeline environment;
 - any relevant changes in the range of potential;
 - in cases of a.c. interference;
 - when there are long-term changes to the electrical interference.

Other measurements, such as line current measurement as described in [Annex A](#), can be necessary for a better understanding of the operating conditions of the cathodic protection system.

Table 9 — Minimum routine measurements and checks periodicities

Item	Action	Periodicity
Impressed-current station	Visual check of the transformer-rectifier unit and reading the output voltage and current	One to three months
Impressed-current station	Comprehensive functional tests of the impressed current station (e.g. verification of transformer-rectifier unit, control of the permanent electrode, resistance determination of the groundbed, measurement of the earthing system, control of instruments) and measurement of the output voltage and current	One to three years
Unidirectional drainage stations	Visual check of the unidirectional drainage unit and reading of the integral cathodic protection instrumentation	One month
Unidirectional drainage stations	Comprehensive functional tests of the unidirectional drainage station (e.g. control of the permanent electrode, functionality of the diodes and their protection devices, setting of resistors, control of instruments) and measurement of the drain point potential and current	One to three years
Connections to foreign structure (resistive or direct bond)	Measurement of current flow	One year
Connections to foreign structure (resistive or direct bond)	Comprehensive functional tests of the device and measurement of the current flow (magnitude and direction) and the potential	One to three years
Grounding systems connected to the pipeline and related to the cathodic protection system or corrosion mitigation system	Comprehensive functional tests of the devices and determination of the groundbed resistance and the current flow through the mitigation system (if any)	One to three years
Permanent reference electrode	Comparison with a reference electrode whose accuracy can be traced to a master electrode	One to six years ^b
Selected test stations	Measurement of E_{ON} potential	One year
All test stations	Measurement of E_{OFF} potential ^a	Three years
Galvanic anode station	Visual check of the stations and measure the pipe-to-electrolyte potential	One year
Galvanic anode station	Comprehensive functional tests of the galvanic station (e.g. resistor setting, efficiency of the bonding connection and measurement of the pipe to electrolyte potential).	Three years
^a Where stray current can influence the E_{OFF} potential measurements, alternative measurement techniques may be considered if demonstrated to be accurate and effective.		
^b The performance and the repeatability of the permanent reference electrode depends upon the type of reference electrode and the frequency of measurements. The periodicity, therefore, can vary between one and six years.		

More frequent measurements can be required e.g. in areas of stray current interference, critical installations and foreign connections.

Less frequent measurements and/or the restriction of measurements to selected test stations may be considered based on results of specialized surveys, e.g. showing the stability of the system with reference to the interference from stray currents, lightning, fluctuating electrolyte conditions, coating degradation, etc.

The risks of an unacceptable level of a.c. interference as defined in 6.4 may be determined by studies or by direct measurements (see EN 15280 for information). After these studies or measurements have been carried out, some test stations may be monitored to also measure a.c. voltages. These measurements may be combined with those in Table 9.

13.4 Remote monitoring

NOTE Remote monitoring can provide facilities such as prompt response to equipment failure and automatic notification of alarm thresholds being exceeded.

If the cathodic protection system is monitored by remote monitoring, and the periodicity of readings is sufficient such that deterioration of the cathodic protection effectiveness or equipment malfunctions can be detected, then the periodicities laid out in [Table 9](#) for field measurements do not apply. Periodicities can be increased, depending on the overall coating quality of pipeline, the external environment of the pipeline (e.g. interference with a.c. or d.c. sources) and the number and distribution of remote monitoring installations.

As a minimum, remote monitoring shall give the same level of information as obtained from cathodic protection operators in the field.

Results provided by the remote monitoring system should be periodically checked to confirm that the remote monitoring system is functioning correctly.

Design and implementation of remote monitoring shall be in accordance with national or local regulations.

13.5 Specialized surveys

The requirement for and periodicity of specialized surveys shall be based on inspection results and pipeline history. These surveys should be carried out by personnel using purpose-built equipment and instrumentation under supervision of trained personnel. Such surveys are recommended when excessive coating damage is suspected and/or localized areas of inefficient cathodic protection are observed.

These surveys should be carried out at the early stage for new pipelines. For existing pipelines, the frequency should take into account information from other inspection methods.

[Annex D](#) provides information on possible specialized surveys.

13.6 Monitoring plan

A monitoring plan for the cathodic protection system shall be implemented and maintained.

The monitoring plan shall include at least the following:

- description of the measurements to be taken;
- locations where these measurements are to be conducted;
- monitoring equipment required to conduct such surveys;
- measurement techniques to be used;
- frequency with which each type of measurement shall be performed.

This monitoring plan can also include remote monitoring system installed on the pipelines.

NOTE The weather conditions or the seasonal conditions can have an impact on the results of the measurements.

13.7 Monitoring equipment

Potential measurements shall be carried out with a reference electrode and a voltmeter. The input impedance of the voltmeter should be high enough to prevent effects on the measurement value by the instrument. This input impedance should be at least 1 M Ω to and should normally not exceed 10 M Ω .

NOTE 1 The input impedance depends on different parameters such as the exchange surface area of the reference electrode used, the quality of the contact between the reference electrode and the soil, and the soil resistivity.

NOTE 2 The higher the impedance, the better the accuracy of the measurement.

Reference electrodes shall be designed in such a manner that their potential is not affected during voltage measurement.

Voltmeters used for measurements should have an appropriate accuracy for the potential to be measured. Typical accuracies are ± 1 % for digital meters and ± 2 % of the full scale deflection for analogue meters.

The accuracies of the current measurements carried out using a shunt and a voltmeter or using an ammeter (excluding clamps) should be better than $\pm 2,5$ % if the intensity of the current is lower than 10 A, and better than ± 5 % above 10 A. The shunt value, whether it is internal or external to the measuring instrument, should take into consideration the likely effect of the inclusion of the shunt resistance in the circuit being measured.

The measurement requirements and accuracies shall also apply for remote monitoring, data loggers, voltmeters, or ammeters.

In case of presence of a.c. interference, instruments should be combined with a suitable a.c. filter in order to measure only the d.c. component and to take into account the delay caused by the filter.

The sample time of the instruments used should be related to the kind of measurements carried out and the type of electrical influence on the pipeline.

Multimeters and reference electrodes used for cathodic protection measurements on the field shall be periodically checked in accordance with ISO 10012.

13.8 Maintenance and repair

Effectiveness of the cathodic protection system shall be maintained throughout the lifetime of a pipeline. Remedial actions shall be taken if periodic tests and inspections indicate that protection is no longer adequate.

Potentials that do not meet the criteria stated in [Clause 6](#) shall be investigated and all deficiencies corrected as soon as practical. Origins of significant positive shifts in pipeline potential, such as those due to stray-current interaction, shall be investigated and a solution shall be proposed as soon as possible.

Isolating devices sited above-ground and open to the weather (e.g. insulated flanges and polarization cells) should be inspected periodically and cleared of any accumulated debris that can bridge the insulation material. Any protective barrier coating applied to prevent the ingress of dirt or absorption of water by insulating materials shall be kept in good condition. Care shall be taken to ensure that isolating devices are not unintentionally electrically by-passed after installation.

Whenever the effectiveness of an isolating device is tested on site, the integrity of any accompanying high-voltage protection device shall also be checked in accordance with the manufacturer's instructions (e.g. surge protective device in parallel with an isolating joint).

14 Documentation

14.1 Design documentation

14.1.1 General

The purpose of documentation is to maintain a complete record of the design process. This will include details of any design assumptions or values used in the design. In this sense, documentation can be in electronic format.

Where relevant, the design documentation should include the following:

- the extent of the pipeline to be cathodically protected;
- assumptions regarding foreign contacts (e.g. earthing systems);

- details of the coating systems used;
- anticipated coating deterioration over the design life;
- estimated current density required to achieve cathodic protection;
- electrolyte investigation results (resistivity, bacterial activity, pH);
- schedule of foreign crossings;
- availability of power supplies for impressed current systems;
- assumptions regarding the risk of a.c. or d.c. interferences;
- schedule of adjacent cathodic protection systems and an assessment of the risk of interference;
- results of current drainage (injection) tests;
- description of the cathodic protection system, including a schematic diagram;
- statement of the protection criteria;
- test, measurement and monitoring facilities to be incorporated;
- details of any bonds;
- specifications for the proposed materials;
- calculations to show how the current requirements have been derived;
- calculations to show the groundbed resistance and life-time expectancy;
- pipeline attenuation calculations;
- schedule of materials;
- design drawings;
- installation procedures;
- commissioning procedures.

14.1.2 Construction details and installation procedures

Full construction details and installation procedures of the cathodic protection system shall be documented to ensure that the system will meet the performance requirements of the design and the local electrical safety regulations.

These should include the following:

- procedures for the installation of d.c. voltage sources, groundbeds, cables, test facilities, cable connections to the pipeline;
- procedures for all tests required to demonstrate that the quality of the installation meets the requirements;
- procedures and criteria to show that there is no adverse interference effect either to, or from, the pipeline being protected;
- procedure to demonstrate that there are no adverse effects caused by a.c. interferences;
- construction drawings including, but not limited to, plot plans, locations of cathodic protection stations and test facilities, cable routing, single-line schematics, wiring diagrams and groundbed construction, and civil works;

- procedures to ensure safe systems of work during the installation and operation of the cathodic protection system.

14.2 Commissioning documentation

After the successful commissioning of the cathodic protection system, the following shall be compiled in a commissioning report:

- as-built layout drawings of the pipeline including neighbouring structures or systems that are relevant to the effective cathodic protection of the pipeline;
- as-built drawings, reports, and other details pertaining to the cathodic protection of the pipeline;
- records of the interference tests (if any) carried out with neighbouring structures;
- record of a.c. interference tests and any remedial works;
- the voltage and current at which each cathodic protection system was initially set and the voltage and current levels for use during future interference tests; the location and type of interference-current sources (if any);
- records of the pipe-to-electrolyte potentials at all selected test stations before and after the application of cathodic protection;
- records of any coupons or probes that have been installed;
- records of any bond currents;
- records of functional performance of any drainage stations that have been installed;
- test results for any monobloc isolation joints or flange-insulation kits;
- test results for any cased crossings;
- records of any other tests carried out.

14.3 Operating and maintenance documentation

14.3.1 General

An operating and maintenance manual shall be prepared to ensure that suitable operating and maintenance procedures are available for operators. This document shall consist of the following:

- description of the system and system components;
- commissioning report;
- as-built drawings;
- manufacturer's documentation;
- schedule of all monitoring facilities;
- potential criteria for the system;
- monitoring plan;
- monitoring schedules and requirements for monitoring equipment;
- inspection and monitoring procedures for each of the types of monitoring facilities installed on the pipeline;
- guidelines for the safe operation of the cathodic protection system.

14.3.2 Inspection and monitoring data

The results of all inspection and monitoring checks shall be recorded, archived, and evaluated by a competent specialist. The inspection and monitoring checks shall include as a minimum all of the results of measurements in [13.2](#) as well as any other measurements undertaken during monitoring and specialized surveys.

NOTE The results are used to establish a baseline for future verifications of cathodic protection effectiveness and interference.

14.3.3 Maintenance records

For maintenance of the external corrosion protection system (cathodic protection, coatings, and ancillary devices), the following information shall be recorded:

- repair of rectifiers and other d.c. power sources;
- repair or replacement of anodes, connections, and cables;
- maintenance, repair and replacement of coating, isolating devices, test leads, and other test facilities;
- improvement of the cathodic protection system;
- repair or replacement of drainage stations, casing, a.c. mitigation devices, and remote monitoring equipment.

Annex A (normative)

Cathodic protection measurements

A.1 General

Measurements of the following electrical parameters shall be carried out during commissioning and operation:

- rectifier output voltage and current;
- ON- and, if practical, OFF- pipe-to-electrolyte (e.g. soil) potentials;
- ON- and OFF-potential and current flow at coupons, if any;
- effectiveness of any electrical isolation (e.g. isolation joint, casing, spark gaps, etc.);
- ON-potentials on bonded foreign pipelines and the magnitude of the current flow to or from them;
- effect of any d.c. interference with a foreign pipeline;
- effect of any a.c. or d.c. interference current from a foreign source;
- corrosion rate on ER probes if any.

NOTE A typical scheme for detecting faults in an impressed-current CP system is given in [Annex C](#).

A.2 Potential measurements

A.2.1 General

The effectiveness of the CP may be assessed by potential measurement, i.e. OFF-potential measurements which approach the potential at the pipe-to-electrolyte interface with respect to a reference electrode.

The chosen technique should be selected on the basis of local conditions in the field, e.g. the coating type and quality, the electrolyte resistivity and the presence of interference currents, equalizing currents, telluric currents, etc.

NOTE 1 Where current is flowing through the electrolyte and on to the pipeline, there is an ohmic or IR drop in the electrolyte and through the coating. Thus, the potential measurement with the reference electrode at the ground surface includes a contribution from the IR drop. There are complementary techniques that can be used to give a more accurate assessment of the effectiveness of the CP.

NOTE 2 Where the only currents flowing in the electrolyte are from the pipeline's own CP system, the potentials measured at the surface of the ground are generally more negative than the potential at the pipe-to-electrolyte interface.

A.2.2 ON-potential measurement

ON-potential measurements shall be taken with the cathodic protection system continuously operating.

In the case of cathodic protection currents from the pipeline's own protective systems, the potential measured at the ground surface is more negative than the potential measured with a reference electrode positioned in the immediate vicinity of the bare metal of the pipeline (e.g. at a coating defect of a coated pipeline). In low-resistivity electrolytes, the IR drop caused by these currents can reach several tens of

millivolts, while in high-resistivity electrolytes, it can reach a few volts. To minimize IR drop, a reference electrode should be placed as close to the pipe as possible.

NOTE The values obtained contain various unknown IR drops that change with time and position of the measurement. The readings might not reflect the potential at the pipe-to-electrolyte interface.

A.2.3 OFF-potential measurement

By correct use of the OFF-potential technique, measurement errors caused by IR drop in the measurement circuit is significantly reduced.

For buried pipelines, the potential measured with respect to a reference electrode shall be measured after all the currents in the cathodic protection circuit have stopped but before the pipeline has depolarized (see § A.2.5 in case of use of coupon or probe).

For an effective OFF-potential measurement, all sources of cathodic protection current affecting the area under test shall be interrupted simultaneously.

If rapid depolarization occurs or if there is a risk of cathodic over-protection, the instant-OFF potentials shall be determined using a high-speed measuring system such as a data logger or oscilloscope. The sample rate should be determined by taking into account the possibility of potential spikes on the pipeline (caused by stored energy/equalising currents) that do not exist to the same extent as when performing this measurement on coupons.

The OFF-potential shall be measured with a high input impedance instrument (typically 10 M Ω) with a sample period and filtering that is consistent with the ON/OFF switching ratio. The measuring system should be synchronized with the switching system so that the switching actions can be identified and matched to the potential. An oscilloscope may also be used.

A.2.4 Measurements of d.c. true current in low-voltage circuits

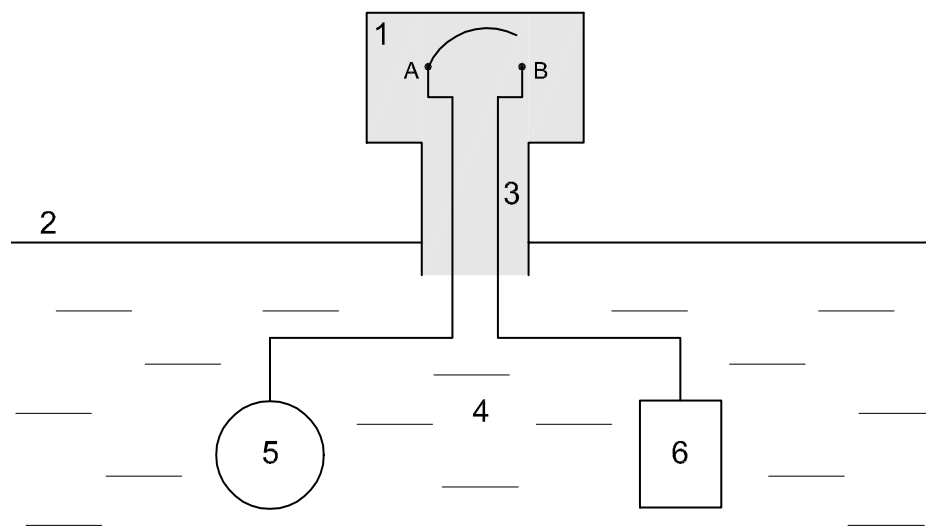
Current measurements may be made either by means of direct measurement of a shunt potential, an ammeter or by means of a clamp/clip ammeter to determine the current flow.

The selection of the shunt value, whether it is internal or external to the measuring instrument, should take into consideration the likely effect of the inclusion of the shunt resistance in the circuit being measured.

The accuracy of the measurement should be better than 2,5 %.

Clamp/clip ammeters should be carefully selected and operated to provide acceptable levels of accuracy.

When low current measurements are required in low-voltage circuits, then the principles and circuits shown in [Figure A.1](#) may be used if stray currents are not present. Alternatively, a zero resistance ammeter may be used.

**Key**

- A, B terminals
- 1 bond
- 2 ground level
- 3 test station
- 4 electrolyte (soil, etc.)
- 5 pipeline
- 6 secondary structure (galvanic anode)

Figure A.1 — Method for determining true current flow in very low-voltage circuits

The procedure for determining d.c. true current measurements in low voltage circuits shall be as follows.

- a) Remove bond between terminals A and B.
- b) Measure voltage, U_1 , across AB with high-impedance millivoltmeter.
- c) Connect ammeter across AB and measure current, I .
- d) Measure voltage, U_2 , across AB with ammeter still connected.
- e) Calculate true current, I_{true} , from Formula (A.1):

$$I_{\text{true}} = I \times \frac{U_1}{U_2 - U_1} \quad (\text{A.1})$$

A.2.5 Test probe or coupon measurements

Probes or coupons should be manufactured from a material similar to the pipeline under test and have a similar coating, except for a defined area that is left bare. Probes or coupons connected to the pipeline shall have an accessible test link which can be temporarily disconnected.

For d.c. problems, the surface area of the coupon or probe should be representative of the average size of expected pipeline coating defects. For a.c. problems, the surface area of the coupon or probe should be 1 cm².

OFF-potential measurements should be taken immediately after the test probe or coupon is disconnected from the pipe and without interrupting the sources of protective current.

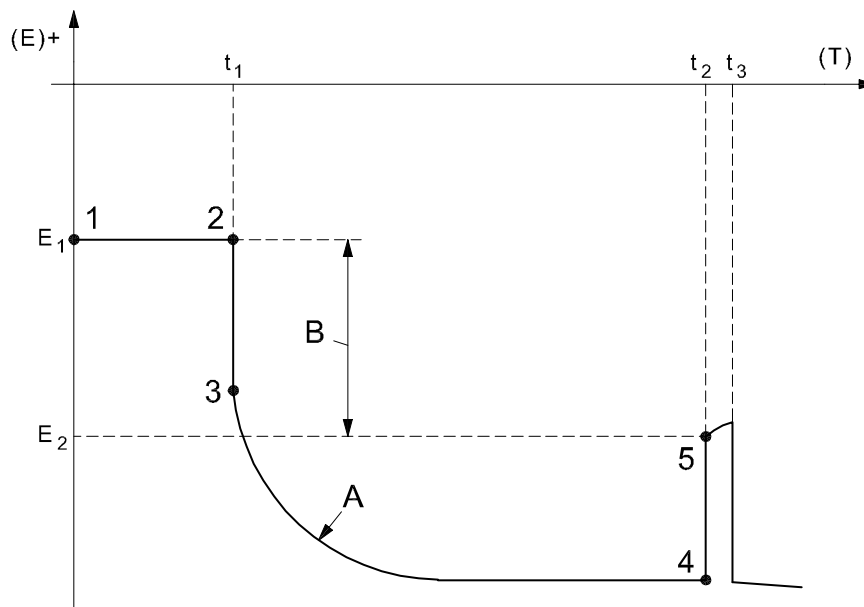
NOTE 1 It can be assumed that the coupon or probe metal adopts a potential with respect to the adjacent electrolyte that is similar to the pipe-to-electrolyte, potential at a coating defect with the same size on the pipe situated near the coupon.

NOTE 2 When a coupon is used, despite there being no current flowing to it directly when it is disconnected from the pipe, current is still flowing in the surrounding electrolyte. Consequently, there can still be a significant contribution to the measured coupon potential from the IR drop in the electrolyte. Coupon OFF-potentials are more accurate if measured against a permanent reference electrode buried close to the coupon or permanently built in as a facility. The residual IR drop can also be minimized by placing the portable reference electrode in an electrolyte tube that has one end positioned near the coupon and is extended to the surface.

A.3 100 mV cathodic potential shift

A.3.1 Measurement method during polarization

Using the polarization measurement method, the 100 mV cathodic potential shift shall be measured with respect to the free corrosion potential (E_{cor}) according to the Figure A.2. This method applies to a pipeline or a coupon that has not been previously polarized.



Key

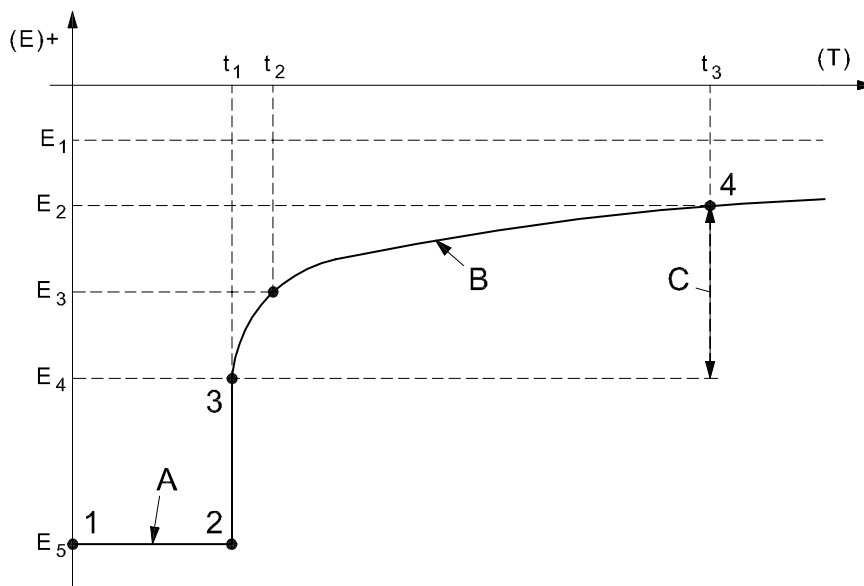
- A polarization formation curve
- B amount of polarization formation
- E_1 free corrosion potential, E_{cor} (marked 1 on the curve)
- E_2 E_{OFF} after t_2 (marked 5 on the curve)
- t_1 time at which cathodic protection is applied to the pipeline or coupon connection
- t_2 time at which cathodic protection is switched off or the coupon is disconnected
- t_3 time at which cathodic protection is switched on or the coupon is connected
- X time, t
- Y potential, E
- 2 - 3 IR drop when cathodic protection is applied to the pipeline or coupon connection
- 4 - 5 IR drop when cathodic protection is switched off or the coupon is disconnected
- 4 E_{ON} at instant t_2

Figure A.2 — Polarization formation method

The amount of polarization formation is the difference between the E_{cor} potential and the E_{OFF} potential measurement.

A.3.2 Measurement method during depolarisation

Using the depolarization measurement method, the 100 mV cathodic potential shift shall be measured with respect to the OFF-potential, E_{OFF} , according to Figure A.3. This method applies on a pipeline or a coupon that is already under protection.



Key

- A cathodic protection is applied
- B depolarization (or polarization decay) curve
- C amount of depolarization (amount of polarization decay)
- E₁ free corrosion potential, E_{COR}
- E₂ pipe-to-electrolyte potential at t_3 (marked 4 on the curve)
- E₃ E_{OFF}
- E₄ instant- E_{OFF}
- E₅ E_{ON} (marked 1 on the curve)
- t₁ time at which cathodic protection is switched off or the coupon is disconnected
- t₂ time at which the E_{OFF} measurement is carried out
- t₃ time at which the potential is measured and which will be used to calculate the amount of depolarization
- X time, t
- Y potential, E
- 2 - 3 IR drop when cathodic protection is switched off or the coupon is disconnected

Figure A.3 — Polarization decay method

The amount of depolarization is the difference between the E_{OFF} potential and the $E(t_2)$ potential.

A.4 Measurement of corrosion rate

The effectiveness of the cathodic protection may be assessed by corrosion rate measurements on probes (e.g. ER probes).

A.5 Control of electrical isolation

A.5.1 General

Failures of isolating joints to perform satisfactorily can be due to any of the following:

- defective isolating joint itself or defective isolating flange kit components;
- external conductive connection between both sides of the isolating joint, e.g. via pipe supports, other piping, or the local earthing;
- degradation or lack of internal coating where the pipeline is carrying an electrically conductive fluid.

Several measurement methods that may be used to determine the effectiveness of an installed isolating joint or isolating flange kit are provided in [A.5.2](#) through [A.5.6](#). A combination of two or more of the methods can provide more certainty.

A.5.2 Pipe-to-electrolyte potential measurements

Pipeline-to-electrolyte potentials shall be measured on both sides of an isolating joint. If there is a significant difference in potential, the isolating joint/isolating flange is effective. A partially defective isolating device cannot be readily identified as being defective, since the potential on both sides of the joint can still be different. As a general guide, a potential difference of less than 100 mV may be regarded as inconclusive.

A.5.3 Electrical resistance measurements

Direct measurements of electrical resistance shall be carried out with an a.c. resistance meter.

NOTE 1 The d.c. resistance meters give false indications due to polarization effects between the pipeline and the soil, in parallel with the isolating joint.

NOTE 2 The interpretation of the results of direct resistance measurements at installed isolating joints can be difficult. This is because the resistance of the pipe (or structure) to earth and, if the pipeline carries a conductive solution, the internal resistance of the conductive fluid (electrolyte), are both parallel to the resistance of the isolating joint. The actual resistance measured can, therefore, be a combination of these three and the measurement of a low-resistance value is not always a reliable indication that the isolating device is defective.

Where an isolating flange kit has been installed, the satisfactory insulation of each bolt should be checked with each flange using an ohm-meter or other similar device because the electrical isolation of a bolt can be efficient on one flange and deficient on the other.

A.5.4 Impressed-current tests

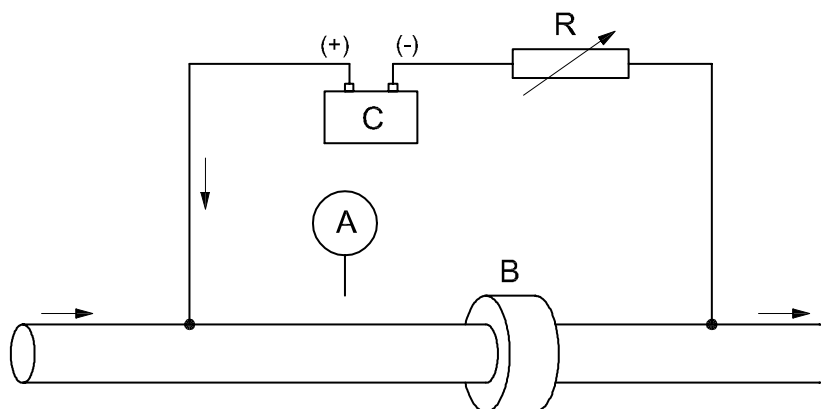
When using impressed-current tests to verify the integrity of an isolating device, one of the following methods shall be used:

- Method 1, in which current is applied to the pipeline on one side of the isolating device. If the potential on the other side of the isolating device does not change or changes in value in the opposite direction (due to an interference effect), then the isolating device may be considered to be effective. Potential measurements by adding an automatic interrupter on the impressed current may help to confirm it;
- Method 2, in which the current through a temporary bond across the isolating device is measured while CP is applied to one side only. If there is no current flow through the bond, then the isolating device may be considered defective or being by-passed. A partially defective isolating device might not be readily identifiable by this method, since the current in the bond might not be zero if the leakage resistance and the bond resistance have similar magnitudes.

A.5.5 Audio-frequency generator measurements

Audio-frequency generator measurements shall be carried out by introducing a suitable audio frequency from a frequency generator on one side of the isolating joint (e.g. by a conventional pipe locator) and attempting to trace the signal on the opposite side of the isolating device.

A.5.6 Test of isolating joint with the use of battery and ammeter clamp



Key

- A clamp
- B isolating joint
- C battery
- R low adjustable resistor

Figure A.4 — Test of isolating joint with battery and clamp

Initially, the reference current delivered by a battery shall be measured as reference for the test being performed (see [Figure A.4](#)). This measurement may be made with a low value adjustable resistor (e.g. 12 Ω for a 12 V battery) by reducing the resistance to get the short-circuit current with the battery which is the reference current. A d.c. voltage shall be applied with the battery between both sides of the isolating joint. The current delivered by the battery shall be measured.

A d.c. ammeter clamp shall be installed on the pipe on one side of the isolating joint in order to measure the d.c. current flowing on the pipe between the isolating joint and the connection of the battery.

If the current measured by the clamp is equivalent or close to the current applied, the isolating joint is ineffective. If the current measured by the clamp is zero or very small in relation to the reference current of the battery, the electrical insulation of the isolating joint is effective.

A.6 Determination of line current

Measurements carried out at line current monitoring test stations are an effective way of monitoring and assessing the cathodic protection of a pipeline, e.g. for localizing faults in cathodic protected systems and for assessing coating quality.

Line-current monitoring testers should be installed at regular distances (approx. every 10 km) on the pipeline and should also be installed at selected locations such as the following:

- cathodic protection stations to evaluate current distribution;
- large river crossings;
- branch lines.

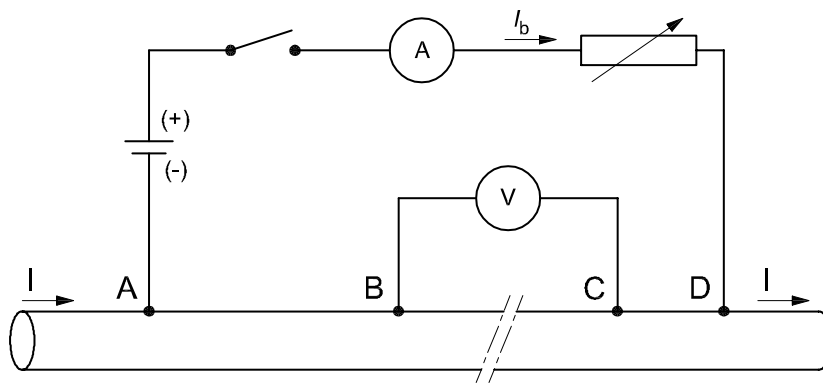
The method shall be as described in [Figure A.5](#).

If current I_b is adjusted to give no deflection on the micro voltmeter, then $I_b = I$.

A and D are current carrying cables used for calibration purposes. B and C are potential measuring cables. The distance between B and C shall be selected to provide meaningful data of current flow in the selected section. The distance shall be sufficient such that the magnitude of the voltage drop is within the range of the instrumentation. Typical distances are between 30 m and 100 m. The cable to pipe connections B and C should be connected at least 10 cm from the current injection points A and D.

Current (I_b) shall be applied to the pipeline section between points A and D using a power source (battery), and the voltage (U) shall be measured between points B and C. In order to avoid interference caused by other currents flowing through the pipeline as well as contact voltages, the power source shall be switched on and off and the voltage (ΔU) and the current (ΔI_b) shall be used for calculation purposes. The longitudinal resistance between B and C shall then be determined using Formula (A.2):

$$R_{BC} = \frac{\Delta U}{\Delta I_b} \tag{A.2}$$



Key

- A current carrying cable
- B potential measuring cable
- C potential measuring cable
- D current carrying cable
- I pipeline current
- I_b current applied to the pipeline section between points A and D

Figure A.5 — Measuring circuit for determining the line current and the longitudinal resistance of a pipeline

Annex B (normative)

Electrical interference

B.1 General

Electrical interference can be from d.c. or a.c.

Sources of d.c. interference are the following:

- constant current (e.g. adjacent cathodic protection systems);
- fluctuating current (e.g. d.c. traction systems, coal mine haulage systems and pumps, welding machines, and direct current power systems);
- d.c. telluric currents (naturally occurring geomagnetic currents).

Sources of a.c. interference are the following:

- short-term interference, caused by faults in a.c. power systems and electrified railways;
- long-term interference, caused by inductive or conductive coupling between the pipeline and high-voltage lines or electrified railways.

Examples of stray currents include d.c. or a.c. from traction systems or d.c. from external cathodic protection systems. Induced currents are not considered as stray currents. The corrosion mechanisms for a.c. and d.c. are different and are dealt with in detail in EN 50122-1, EN 50122-2, EN 50122-3, EN 50162, and EN 15280.

NOTE 1 a.c. interference manifests itself by the presence of a.c. voltages on the pipeline, usually by induction.

NOTE 2 d.c. interference manifests itself by changes in the pipe-to-electrolyte potentials.

B.2 d.c. interference

B.2.1 Measurements

In areas where d.c. interference is suspected, one or more of the following shall be performed:

- measure pipe-to-electrolyte potentials over an extended period of time to capture the pattern, magnitude, and nature of the interference;
- measure current magnitude and direction on coupons connected to the pipeline;
- measure current magnitude and direction flowing in the pipeline with recording or indicating instruments (see [Annex A](#));
- measure amplitudes of variations in current output of the suspected source of interference current, or measure the potential of the interfering structure (e.g. railway road), and correlate them with measurements obtained in a), b), or c) above;
- calculate the actual corrosion rate using an ER probe.

The measurements should be carried out for a period suitable for the interference phenomenon being investigated to assess the time dependence of the interference level. A typical period is 24 h.

In the case of interference caused by cathodic protection systems on a non-protected structure, the interference measurements shall be conducted as follows.

- Measure both the foreign pipeline and the interfering pipeline pipe-to-electrolyte potential while the relevant sources of cathodic protection current that can cause interference are, preferably simultaneously, energized then interrupted. Measurement should not contain errors caused by equalizing currents or foreign galvanic couples.

NOTE EN 13509^[9] provides details of measurement errors.

- Measure anodic shifts including IR drops (caused by d.c. stray currents) for pipelines that are not cathodically protected according to the electrolyte resistivity. Maximum acceptable anodic shifts are:
 - for steel and cast iron:
 - 300 mV with a electrolyte resistivity greater than or equal to 200 $\Omega\cdot\text{m}$;
 - 1,5 times the resistivity value with a electrolyte resistivity between 15 $\Omega\cdot\text{m}$ and 200 $\Omega\cdot\text{m}$;
 - 20 mV with a electrolyte resistivity below 15 $\Omega\cdot\text{m}$.
 - 200 mV for steel buried in concrete.

For cathodically protected pipelines, anodic shifts are acceptable provided that the cathodic protection criteria range is maintained.

If an isolating joint is installed in an area of electrical interference, there can be additional corrosion risks (see 7.3).

B.2.2 Mitigation of d.c. interference corrosion problems

In the case of interference from cathodic protection systems, some common methods that may be considered in resolving interference problems on pipelines or other buried structures include the following:

- prevention of pick-up or limitation of flow of interfering current through a buried pipeline by improved isolation or shielding;
- augmentation or re-distribution of the cathodic protection current sources;
- installation of metallic bonds (with or without a resistor in the metallic bond circuit) between the affected pipelines or other structures; the metallic bond electrically conducts interference current from an affected pipeline to the interfering pipeline and/or current source;
- application of unidirectional control devices, such as diodes or reverse current switches;
- adjustment of the current output from mutually interfering cathodic protection rectifiers;
- installing properly located isolating joints in the affected pipeline; isolating joints should not be installed where there is a risk of accelerating corrosion at the joint (i.e. avoid areas where electrolyte potential gradients are high);
- use of galvanic anodes on the anodic section.

In the case of interference from d.c. traction systems (e.g. railways or trams), stray currents should be reduced as much as possible at the source. d.c. interference can be mitigated for example by:

- minimizing the distance between traction sub-stations;
- ensuring low resistance return circuits (typically less than 0,03 Ω/km);
- ensuring high resistance between return rail and earth by the use of floating earth systems;
- using stray current collection mats;

- using clean, well-drained ballast;
- installing drainages on railways to neutralize influences when negative railway potential values exists;
- installing automatic impressed current station to neutralize the electrical influence in the anodic areas;
- installing rectifiers on railways to neutralize influences that cannot be locally reduced by drainage (economical aspect).

NOTE Further guidance on methods for mitigating d.c. interference corrosion is given in EN 50162 and EN 50122 (all parts).

B.3 a.c. interference

B.3.1 General

The magnitude of permanent or short-term interference on a pipeline from high-voltage a.c. sources such as power lines and electrified railways mainly depends on the following:

- length of parallel or quasi parallel routing;
- distance between the pipeline and the interfering source;
- electrolyte resistivity along the routing of the pipeline;
- a.c. line voltage level;
- a.c. line current level;
- pipeline coating quality.

NOTE 1 a.c. interference effects on buried pipelines can cause safety problems.

NOTE 2 See EN 50443 for possible effects associated with a.c. interference to pipelines include electric shocks, damage to coating, and damage to insulators.

NOTE 3 EN 15280 gives detailed guidelines on a.c. corrosion under normal operating conditions.

B.3.2 Calculation of a.c. induction and/or conduction effect

a.c. interference from traction systems or power lines may be simulated on a computer taking into consideration data from the source of interference and the affected pipeline such as coating resistance, diameter, route, and locations of isolating joints or isolating flanges.

Data for consideration are the interfering high voltage, operating current, location and layout of the high-voltage tower and position of the wires, route (including the position of the transformers), frequency, and electrical characteristics.

B.3.3 Measurements

To determine the a.c. corrosion risk, coupons should be installed where the a.c. current density can be significant. These locations may be deduced either from modelling, site measurements, or practical experience. Coupons should be buried at the pipeline depth and be configured for current measurements. Installation of corrosion probes should also be considered.

NOTE 1 The a.c. current density through a coating defect is a determining factor in assessing the a.c. corrosion risk.

NOTE 2 If the a.c. current density on a 1 cm² bare surface (e.g. an external test probe) is higher than 30 A/m², there is an increased risk of a.c. corrosion.

Measurements should include

- pipe or coupon-to-electrolyte potential (a.c. and d.c.), and
- coupon current (a.c. and d.c.).

From these measurements, it is possible to calculate the a.c. and d.c. current densities and the current density ratio (a.c. current density divided by d.c. current density). These parameters should be used to assess the a.c. corrosion risk.

B.3.4 Limiting a.c. interferences

The maximum step and touch voltage shall be limited in accordance with local or national safety requirements and shall be adhered to at all locations where a person can touch the pipeline or a pipeline component. Such measures are outside the scope of this part of ISO 15589, but they must be taken into account when considering the overall a.c. mitigation.

Protection measures against a.c. corrosion should be achieved by reducing the induced a.c. voltage.

To reduce the a.c. voltage (both in operating and fault conditions), the pipeline should be connected to an earthing system. d.c. decoupling devices are required if there will be any adverse effect on the cathodic protection system.

Annex C (informative)

Fault detection of impressed-current systems during operation

If abnormal values of potential and current are observed in impressed-current systems, a comparison with earlier values can indicate the nature of the fault, as given in [Table C.1](#).

Table C.1 — Possible causes of abnormal observations

Observation	Possible cause
Pipe-to-electrolyte potential becomes more positive as protection system is switched on	1) reversed connections at the transformer-rectifier, which is a very serious fault that could result in severe damage to the pipeline in a relatively short period of time
Applied voltage zero or very low, current zero	1) failure of a.c. fuse or tripping of other protective device 2) failure of a.c. supply 3) failure of transformer-rectifier
Applied voltage normal, current low but not zero	1) deterioration of anodes or groundbed 2) drying out of electrolyte around groundbed 3) accumulation of electrolytically produced gas around the anodes (gas blocking) 4) disconnection of individual anodes in a groundbed or anode system 5) disconnection of part of the protected pipeline from the negative side of the transformer-rectifier
Applied voltage normal, but current zero	1) severance of anode or cathode cables 2) failure of d.c. fuse or ammeter of transformer-rectifier 3) complete failure of groundbed or anode system
Applied voltage and current zero	1) control on transformer-rectifier unit set too low 2) transformer or rectifier fault 3) electricity supply fault
Applied voltage and current both high	1) control on transformer-rectifier set too high 2) drift of permanent reference electrode in positive direction 3) disconnection of permanent reference electrode

Table C.1 (continued)

Observation	Possible cause
Applied voltage and current normal but pipe-to-electrolyte potential insufficiently negative, i.e. too positive	<ol style="list-style-type: none"> 1) break in a continuity bond, or increased resistance between point of connection and point of test due to a poor cable connection 2) greatly increased aeration of the electrolyte at or near the point of measurement due to drought or increased local ground drainage 3) faulty isolation equipment, e.g. the short-circuiting of an isolating joint at the end of the pipeline being protected 4) protected pipeline shielded or otherwise affected by new pipelines 5) failure of CP system on an adjacent section of the pipeline or on a secondary pipeline bonded to it 6) deterioration of, or damage to, the pipeline protective coating 7) addition or extension to the buried pipeline, including contact with other metallic structures 8) interaction with the CP system on an adjacent or neighbouring pipeline 9) effects of interference current on the pipeline
Applied voltage and current normal but the pipe-to-electrolyte potential abnormally negative	<ol style="list-style-type: none"> 1) break in the continuity bonding at position further from the point of application than the point of test 2) secondary pipelines have been disconnected or disbonded from the pipeline being protected, or have received additional protection via a new CP system 3) effects of interference current on the pipeline
Applied voltage and current normal but pipe-to-electrolyte potential fluctuates	<ol style="list-style-type: none"> 1) presence of interference earth currents, e.g. interference from d.c. traction systems or telluric/geomagnetic effects

Annex D (informative)

Description of specialized surveys

D.1 General

This Annex provides information on three types of specialized surveys:

- above-ground surveys used to assess the coating condition and to locate coating defects;
- above-ground surveys used to measure pipe to electrolyte potential along a buried pipeline;
- current requirement tests.

D.2 Above-ground surveys used to assess the coating condition and to locate coating defects

D.2.1 General

Coating defects can be located either by a.c. or d.c. signal measurements. The most well-known are Pearson and current attenuation survey (a.c.) and DCVG (d.c.).

NOTE Poor results can be obtained if ground contact of the pipeline is not sufficient.

D.2.2 Pearson survey (or ACVG)

Pearson surveys (also known as alternating current voltage gradient surveys) locate defects in the protective coating of a buried pipeline.

An a.c. voltage is applied between the pipeline and remote earth and the resulting voltage difference between two electrodes in contact with the electrolyte above the pipeline is measured. For the traditional Pearson survey the electrodes are spaced approximately 6 m to 12 m apart. For modern survey systems, the electrodes are placed on an "A" frame and placed about 1 m apart. The Pearson survey system requires two operators whereas the "A" frame survey requires only one operator.

The selection of the frequency of the applied a.c. signal depends on the pipeline coating type and condition. Lower frequencies are generally used for poor quality coatings.

The Pearson survey system detects the signals radiated from the buried pipeline.

For the traditional Pearson survey, operators walk above the pipeline and make ground contact using cleated boots. As the leading operator approaches a coating defect, the signal gradually increases and peaks as the operator passes over the defect. The signal gradually decreases to a null when the defect is midway between the two operators.

If an "A" frame is used, the ground contact is made by direct contact above the pipeline. Interpretation of the signal results is the same as for the two-operator Pearson survey.

D.2.3 Current-attenuation survey

Current-attenuation surveys can be used to locate zones of defects in protective coatings on buried pipelines. The method is similar to the Pearson survey technique in that an a.c. voltage is applied to the pipe, but a search coil is used to measure the strength of the magnetic field around the pipe resulting from the a.c. signal.

Current-attenuation surveys are based on the assumption that when an a.c. signal flows along a straight conductor (in this case, the pipeline), it produces a symmetrical magnetic field around the pipe. The operator uses the electromagnetic induction to detect and measure the intensity of the signal using an array of sensing coils carried through the magnetic field to compute pipe current. Where the protective coating is in good condition, the current attenuates at a constant rate that depends upon coating properties. Any significant change in the current attenuation rate can indicate a coating defect zone or contact with another metallic structure.

D.2.4 Direct-current voltage gradient survey

A direct-current voltage gradient (DCVG) survey is carried out on buried pipelines to locate and establish the relative severity of defects in protective coatings on buried pipelines.

The system works by applying a cyclically switched direct current to the pipeline, in the same manner as cathodic protection, establishing a voltage gradient in the electrolyte due to the passage of current to the bare steel at coating defects, and measuring the magnitude and direction of the voltage gradients in the electrolyte between two electrodes (usually copper/copper sulfate electrodes).

Generally, the larger the defect, the greater the current flow and voltage gradient.

Either an existing or a temporary impressed current system is used as a source of d.c. to the pipeline. The d.c. source is interrupted cyclically, usually with a longer time for the OFF signal than for the ON signal. This provides a rapidly pulsing d.c. source to achieve a significant potential change on the pipeline that can be easily identified with a millivoltmeter.

Using a sensitive millivoltmeter, the potential difference is measured between two electrodes placed at the surface level in the electrolyte within the voltage gradient. Defects can be located by null readings corresponding with the electrodes being symmetrical either side of the defect. In carrying out the survey, the operator walks the pipeline route taking measurements at typically 1 m to 2 m intervals with the electrodes one in front of the other, 1 m to 2 m apart. The electrodes are normally held parallel to and directly above the pipeline, enabling the determination of the direction of current flow to the defect. To get a proper measurement, it is necessary that both electrodes be in contact with the electrolyte.

When the d.c. current flows to a coating defect, the potential gradient in the electrolyte changes, becoming greater as the defect is approached and decreasing to null when the epicentre of the coating defect is mid-way between the two electrodes.

This method can be difficult to use in the presence of severe stray currents.

D.3 Above-ground surveys used to measure pipe to electrolyte potential along a buried pipeline

D.3.1 Close-interval potential survey

Although test stations are distributed along the length of the pipeline, there is always the possibility that the cathodic protection can be ineffective at some point between test stations.

Close-interval potential survey (CIPS) can be used to determine the level of cathodic protection along the length of the pipeline. It can also indicate areas affected by interference and coating defects. The pipe-to-electrolyte potential is measured at close intervals (typically 1 m) using a high-resistance voltmeter/microcomputer, a reference electrode and a trailing cable connected to the pipeline at the nearest test station. Measurements of potential are plotted versus distance, from which features caused by changes in potential caused by local variations in cathodic protection current density can be identified.

This method cannot be usually used in the presence of stray currents to measure the IR-free potential, unless special survey techniques are used to estimate the IR-free potential.

The survey can be carried out with the cathodic protection system energized continuously (“ON-potential” survey) or with all transformer-rectifiers switching OFF and ON simultaneously with the aid of synchronized interrupters (“ON- and OFF-potential” survey).

In order to achieve a realistic OFF pipe-to-electrolyte potential, it is necessary that the IR drop be reduced to an insignificant level. To do this, it is necessary to synchronously interrupt all the sources of applied d.c. current that could affect the OFF potential measurements (e.g. adjacent transformer rectifiers, equipotential bonds). Synchronous interruption can be achieved by the use of synchronized cyclical switchers.

There is a wide range of proprietary devices available for taking the close interval pipe-to-electrolyte potentials with varying degrees of accuracy. Whichever measurement system is chosen, it is necessary that the system has the ability to either be synchronized to the switchers or to accurately select the time at which a reading is taken.

Because a large amount of data are produced, a field computer or data logger is normally used and the information later downloaded to produce plots of pipeline potential versus distance from the fixed reference point.

D.3.2 Intensive measurement technique

The intensive measurement technique involves simultaneous measurements with a voltmeter connected to the pipeline via a test station and also to two or three electrodes, one over the pipeline, and one or two remote. The technique can provide both coating defect location and IR-free potential measurement. The operator walks along the pipeline and carries out measurements.

This technique can be applied only if the pipeline is within the linear part of the potential gradient caused by the foreign current (remote) source, i.e. where the potential gradients are constant with distance.

The combination of CIPS and perpendicularly measured potential gradients is known as an intensive measurement technique. It can verify the effectiveness of cathodic protection by calculating the IR-free potential (E_{IRfree}) at the pipe-to-electrolyte interface. Typical positioning of electrodes is shown in [Figure D.1](#).

The IR-free potential, E_{IRfree} , is calculated using Formula (D.1):

$$E_{\text{IRfree}} = E_{\text{OFF}} - \frac{\Delta E_{\text{OFF}}}{\Delta E_{\text{ON}} - \Delta E_{\text{OFF}}} \times (E_{\text{ON}} - E_{\text{OFF}}) \quad (\text{D.1})$$

where

- E_{IRfree} is the calculated IR-free potential (see position 1 in [Figure D.1](#));
- E_{ON} is the measured ON-potential at position 2 in [Figure D.1](#);
- E_{OFF} is the measured instant-OFF-potential at position 2 in [Figure D.1](#);
- ΔE_{ON} is the voltage gradient between two positions with rectifiers on, for example:
 $\Delta E_{3/2, \text{ON}}$ is the voltage gradient between position (3 and 2) with rectifiers on;
 $\Delta E_{4/2, \text{ON}}$ is the voltage gradient between position (4 and 2) with rectifiers on;
- ΔE_{OFF} is the voltage gradient between two positions with rectifiers off, for example:
 $\Delta E_{3/2, \text{OFF}}$ is the voltage gradient between position (3 and 2) with rectifiers off;
 $\Delta E_{4/2, \text{OFF}}$ is the voltage gradient between position (4 and 2) with rectifiers off.

Using this method, coating defects are detected where $(\Delta E_{\text{ON}} - \Delta E_{\text{OFF}})$ peaks are measured along the pipeline route. The absolute value of $(\Delta E_{\text{ON}} - \Delta E_{\text{OFF}})$ depends on many factors and is proportional to the size of a coating defect. Normally, all large coating defects can be identified if measurements are made at intervals of 5 m along the pipeline.

For $(\Delta E_{ON} - \Delta E_{OFF}) > 100$ mV, the measured values obtained are usually accurate enough to calculate the IR drop in the electrolyte, and hence E_{IRfree} between positions 1 and 2 in [Figure D.1](#).

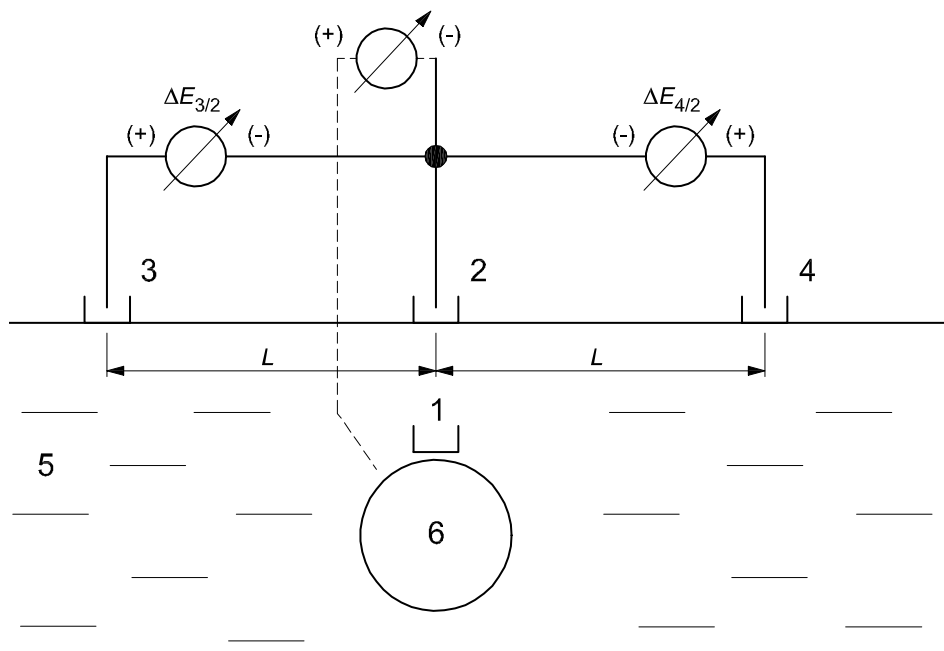
In the presence of equalizing currents, the potential gradients are approximately symmetrical to the pipeline. Therefore, it is sufficient to determine the potential difference between the reference electrodes at points 2 and 3 or at points 2 and 4 in [Figure D.1](#) for determining the ΔE values.

In the presence of currents from remote foreign sources (e.g. stray currents), the potential gradients are no longer symmetrical. The potential gradients caused by coating defects are then the mean values of the potential gradients between the reference electrodes at locations 2 and 3 and at points 2 and 4, arranged symmetrically with the distance, L , in [Figure D.1](#) being the same on both sides. In this case, Formulae (D.2) and (D.3) can be used for determining the field gradients for substitution into Formula (D.1) to determine the IR-free potential.

$$\Delta E_{ON} = \frac{1}{2} \times (\Delta E_{3/2, ON} + \Delta E_{4/2, ON}) \tag{D.2}$$

$$\Delta E_{OFF} = \frac{1}{2} \times (\Delta E_{3/2, OFF} + \Delta E_{4/2, OFF}) \tag{D.3}$$

For currents fluctuating with time, the E and ΔE readings are to be taken simultaneously, both for the ON and the OFF periods.



Key

- 1 electrode at position 1
- 2 electrode at position 2
- 3 electrode at position 3
- 4 electrode at position 4
- 5 electrolyte
- 6 pipe
- 7 cable connected to the pipeline

Figure D.1 — Reference electrode locations for intensive measurement technique

The distance L between electrodes at locations (2) and (3) needs to be selected to cover at least a part of the potential gradient. A distance of typically 5 m to 20 m is sufficient to verify the cathodic protection

effectiveness of large coating defects. The electrodes at positions 1, 2, 3, and 4 are used to measure pipeline-to-electrolyte potentials and potential gradients using the intensive measurement technique.

D.4 Current injection tests

D.4.1 General

Current injection tests can be carried out to

- verify the capability of a cathodic protection system to protect a section of pipeline against corrosion (see D 4.2), and
- evaluate the quality of the coating after construction, especially for a trenchless pipeline section (see D.4.3).

In D.4, guidelines are given that can assist the pipeline operator. Other methods proposed by the pipeline operator can also be used.

D.4.2 Pipeline current and spread resistance requirements

The purpose of this method is to verify if limited pipeline sections can be cathodically protected under the future operating conditions.

For existing pipelines, the information can best be determined from field measurements for better accuracy. For new pipelines, values can be estimated from experience or from the field if available.

Data collection can be restricted to electrolyte resistivities, electrolyte analysis, stray current measurements, and the results obtained from a temporary impressed current cathodic protection system.

Due to different construction process during the laying of a new pipeline, it can be necessary to undertake tests on specific sections to verify that the cathodic protection will be effective.

Typical sections that can require such tests include trenchless installations (e.g. horizontal directional drilling, cased pipelines) and sections isolated for hydrostatic testing.

These tests are normally undertaken before the sections are tied in.

The cathodic protection effectiveness for those pipeline sections can be verified by measurement of the current, I , and the spread resistance, R , of a coating defect based on the protection potentials, E_p .

For this verification procedure of the respective pipeline section, the future operating conditions (regarding E_{ON}) as well as the worst case scenario are to be assumed:

- the value of the current density, j , which is considered as a maximum for achieving the protection potential E_p ;
- maximum value of the electrolyte resistivity, ρ , that is measured or determined in the relevant pipeline route.

With these assumptions, threshold values can be derived for the current demand, I^* , using Formula (D.4) and for the pipeline to electrolyte resistance, R^* , using Formula (D.5):

$$I^* = \frac{16 \times (|E_{ON}| - |E_p|)^2}{j \times \pi \times \rho^2} \quad (D.4)$$

$$R^* = \frac{j \times \pi \times \rho^2}{16 \times (|E_{ON}| - |E_P|)} \quad (D.5)$$

where

- E_{ON} is the ON-potential measured under CP operating conditions, at remote earth, in volts;
- E_P is the expected protection potential, in volts;
- j is the current density on a bare steel surface to achieve E_P , in amperes per square metre;
- ρ is the electrolyte resistivity, in ohm-metres;
- I^* is the maximum current allowed for section, in amperes;
- R^* is the calculated spread resistance of a coating defect in the evaluated section, in ohms;

NOTE These formulae are based on the assumption of a single circular-shaped coating defect. This assumption represents, compared to other theoretical coating defect combinations, the worst-case conditions for the cathodic protection (in absence of a.c. and/or d.c. stray currents). The thickness of the coating is negligible related to the coating defect diameter.

For the verification of cathodic protection effectiveness, it is required that one of the following conditions in Formulae (D.6) or (D.7) be fulfilled:

$$I < I^* \quad (D.6)$$

$$R > R^* \quad (D.7)$$

NOTE These verifications can be applied for the assessment of the cathodic protection of trenchless laid pipeline sections or pipeline sections in casings.

Example calculation for this method using the following input data from field measurements:

- $E_{ON} = -1,5 \text{ V}$
- $E_P = -0,95 \text{ V}$
- $j = 0,1 \text{ A/m}^2$
- $\rho = 50 \text{ } \Omega \cdot \text{m}$
- $I^* = 0,006 \text{ A}$
- $I = 0,0056 \text{ A}$
- $R^* = 89,2 \text{ } \Omega$
- $R = 90 \text{ } \Omega$

Applying Formulae (D.4) to (D.7) results in the following calculations:

$$I^* = 0,006 = \frac{16 \times (1,5 - 0,95)^2}{0,1 \times \pi \times 50^2} \quad (D.8)$$

$$R^* = 89,2 = \frac{\pi \times 0,1 \times 50^2}{16 \times (1,5 - 0,95)} \quad (D.9)$$

$$0,0056 < 0,006 \quad (D.10)$$

90 > 89,2

(D.11)

From the formulae above it can be concluded that Formulae (D.6) and (D.7) are fulfilled, and that the cathodic protection is effective.

D.4.3 Trenchless installation current requirements

This test method provides information regarding the quality of the pipeline coating in a trenchless installation. The test is carried out before tie-in to the remainder of the system .

A current injection test procedure is as follows (all potentials are measured with respect to a copper/copper sulfate reference electrode).

- a) Install a temporary groundbed to provide cathodic protection current to the pipeline section.
- b) Ensure that no exposed areas of the pipe at the section ends are in contact with the soil.
- c) Measure the free corrosion potential of the pipe at each end of the trenchless section;
- d) Apply cathodic protection current in small increments until a potential of $-1,5$ V is achieved at the drain point.
- e) Measure the applied voltage and current.
- f) Measure the potential at the remote end of the pipeline section.
- g) Calculate the surface area of the pipe.
- h) Apply the cathodic protection for at least 10 min and verify that the drain point potential is still approximately $-1,5$ V.
- i) Using a cyclical interrupter (e.g. set to 8 s ON and 2 s OFF), measure the ON and OFF potentials at both ends of the sections under test. The measuring equipment is synchronized with the switching so that actual OFF potentials are measured.
- j) Apply the agreed criterion (usually either a polarized potential or a current density) and if it is not met then apply the cathodic protection continuously for 1 h without interruption and repeat steps i) and j).
- k) If the criteria are not met after one hour, then it is considered that the coating doesn't meet the requirements.

Annex E (informative)

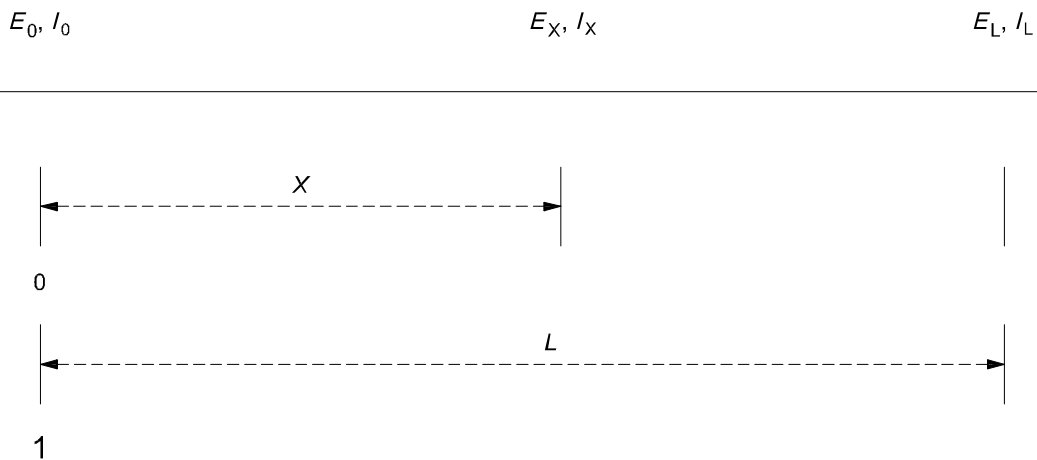
Attenuation of protection

E.1 General

It is possible to obtain an indication of the distribution of the pipe-to-electrolyte potential and the current flowing onto the pipeline with distance from the drain points (the anodes or the cathodic protection impressed current stations) using the schematic shown in [Figure E.1](#) and using Formulae (E.1) to (E.7).

This simplified mathematical approach is based on the following assumptions:

- a linear polarization curve versus current density of the pipeline steel in the electrolyte;
- a constant resistivity of the electrolyte over the length of the pipeline;
- a coating damage uniform over the length of the pipeline.



Key

1 drain point

Figure E.1 — Drain point definition

At every point of the pipeline, the knowledge of the negative potential shift, E_x , due to application of cathodic protection allows the calculation of the potential, U_x , of the pipeline from U_{corr} , the free corrosion potential from the equation: $U_x = U_{corr} - E_x$.

NOTE U_x and U_{corr} are negative or positive numbers. E_x is necessary a positive number.

The attenuation Formulae (E.1) and (E.2) are:

$$E_x = E_0 \cosh \alpha x - R_K I_0 \sinh \alpha x \tag{E.1}$$

$$I_x = I_0 \cosh \alpha x - E_0/R_k \sinh \alpha x \quad (\text{E.2})$$

For a typical pipeline with multiple drain points (anodes) with uniform spacing of $2L$, the potential, E_x , and current, I_x , at any distance x are also given by Formulae (E.3) and (E.4), respectively:

$$E_x = E_0 \times \frac{\cosh \alpha (L-x)}{\cosh \alpha L} \quad (\text{E.3})$$

$$I_x = I_0 \times \frac{\sinh \alpha (L-x)}{\sinh \alpha L} \quad (\text{E.4})$$

where

- E_0 is the pipe-to-electrolyte potential shift (with respect to remote earth) at the drain point (anode), in volts;
- E_x is the pipe-to-electrolyte potential shift (with respect to remote earth) at a distance x from the drain point, in volts;
- E_L is the pipe-to-electrolyte potential shift (with respect to remote earth) at the midpoint L between adjacent anodes, in volts;
- I_0 is the current flowing onto the pipe at the drain point (anode), in amperes;
- I_x is the current flowing onto the pipe at a distance x from the drain point, in amperes;
- I_L is the current flowing onto the pipe at the midpoint L between adjacent anodes, in amperes;
- L is half the distance between drain points, in metres;
- R_k is the characteristic resistance of the section of the pipeline, in ohms, and is equal to $\sqrt{R_L \cdot R_t}$;
- R_L is the linear electrical resistance of the section of the pipeline, in ohms per metre, and is given by: $R_L = \frac{\rho}{A_w}$;
- R_t is the leakage or transverse resistance, in ohm/metres, and is equal to $R_0/\pi D_0$;
- R_0 is the pipe-to-electrolyte insulation resistance, in ohm.square metres;
- ρ is the specific resistance of the pipeline material, in ohm-metres;
- D_0 is the external diameter of the pipeline, in metres;
- A_w is the cross-sectional area of the pipe wall, in square metres;
- α is the attenuation constant for the pipeline section, in reciprocal metres, and is equal to $\sqrt{\frac{R_L}{R_t}}$.

A value for the insulation resistance, R_0 , should be selected based upon practical experience and should consider the following factors:

- type of coating;
- exposure conditions such as seawater or seabed sediments;

ISO 15589-1:2015(E)

- design life of the pipeline, and the anticipated progressive reduction in coating resistance over the design life;
- pipeline installation method and the projected extent of coating damage.

R_L , the linear electrical resistance of the section of the pipeline, can be calculated from Formula (E.5):

$$R = 4 \frac{\rho}{\pi(D_o^2 - D_i^2)} \quad (\text{E.5})$$

where

D_o is the outer diameter of the pipeline;

D_i is the inner diameter of the pipeline;

L is half the distance between drain points, in metres.

Alternatively, values for the electrical resistance for standard pipe sizes may be obtained from tables in the NACE Corrosion Engineer Reference Book.[\[4\]](#)

Annex F (informative)

Electrical tests for isolating joints before installation

The electrical performance of an isolating joint should be tested in laboratory after being produced and in the field, just before being connected to the pipeline.

The electrical tests should be performed after mechanical tests.

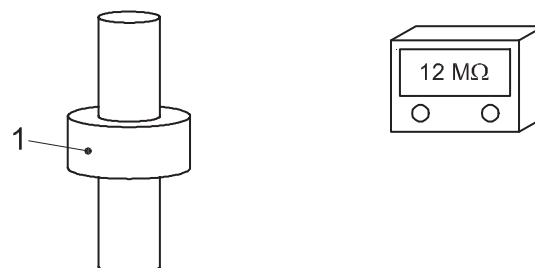
V d.c. (laboratory) Electrical resistance test	V a.c. (laboratory) Dielectric strength test	V a.c. (field before the installation) Electrical resistance test
Electrical test: 1 000 V d.c. for class 1 isolating joint and 500 V d.c. for class 2 isolating joint Resistance test: $\geq 20 \text{ M}\Omega$	Electrical test: For class 1 isolating joint: 2 500 V a.c. r.m.s. per 60 s – no internal or external short circuit For class 2 isolating joint: 1 500 V a.c. r.m.s. per 60 s – no internal or external short circuit	Electrical test: 1 000 V a.c. for class 1 isolating joint and 500 V a.c. for class 2 isolating joint Resistance test: $\geq 5 \text{ M}\Omega$

The isolating joints are classified in 2 categories according to testing with a.c. 50 Hz voltage for 10 s as below:

- class 1: between 2,5 kV and 5 kV r.m.s.;
- class 2: below 2,5 kV r.m.s.

The field test should be performed according to the diagram shown in [Figure F.1](#).

To check the insulation resistance, the isolation joints should be placed in the vertical position in order to avoid short circuit in the electrolyte during the measurement, and the internal and external surface of the joint should be dry. The measurement is performed with a megohmmeter.



Key

- 1 monolithic isolation joints

Figure F.1 — Schema describing a megohmmeter measurement

See Ceacor recommendation named “Isolating joints for gas pipelines”^[3] for detailed information.

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- [12] EN 10329, *Steel tubes and fitting for onshore and offshore pipelines — External field joint coatings*
- [13] EN 12007-1, *Gas supply systems — Pipelines for maximum operating pressure up to and including 16 bar - Part 1: General functional requirements*
- [14] EN 12732, *Gas infrastructure — Welding steel pipework — Functional requirements*
- [15] EN 15257, *Cathodic protection — Competence levels and certification of cathodic protection personnel*
- [16] EN 15280, *Evaluation of a.c. corrosion likelihood of buried pipelines — Application to cathodically protected pipelines*
- [17] EN 50122 (all parts), *Railway applications — Fixed installations — Electrical safety, earthing and the return circuit*
- [18] EN 50162, *Protection against corrosion by stray current from direct current systems*
- [19] EN 50443, *Effects of electromagnetic interference on pipelines caused by high voltage a.c. electric traction systems and/or high voltage a.c. power supply systems*
- [20] NACE SP0572¹⁾, *Standard Recommended Practice — Design, Installation, Operation, and Maintenance of Impressed Current Deep Anode Beds*
- [21] EN 12696, *Cathodic protection of steel in concrete*
- [22] EN 14505, *Cathodic protection of complex structures*

1) NACE, 1440 South Creek Drive, Houston, Texas 77084-4906 USA

**Petroleum, petrochemical and natural
gas industries — Cathodic protection
of pipeline transportation systems —**

**Part 2:
Offshore pipelines**

*Industries du pétrole, de la pétrochimie et du gaz naturel —
Protection cathodique des systèmes de transport par conduites —
Partie 2: Conduites en mer*

Contents

	Page
Foreword	v
Introduction	vi
1 Scope	1
2 Normative references	1
3 Terms and definitions	2
4 Symbols and abbreviated terms	4
4.1 Symbols.....	4
4.2 Abbreviated terms.....	4
5 General	5
5.1 Competence assurance.....	5
5.2 Compliance.....	5
6 Cathodic protection system requirements	5
6.1 General.....	5
6.2 Selection of CP systems.....	6
6.3 Isolating joints.....	6
7 Design parameters	7
7.1 General.....	7
7.2 Protection potentials.....	8
7.3 Design life.....	10
7.4 Design current densities for bare steel.....	10
7.5 Coating breakdown factors.....	12
8 Galvanic anodes	15
8.1 Design of system.....	15
8.2 Selection of anode material.....	16
8.3 Electrochemical properties.....	17
8.4 Anode shape and utilization factor.....	17
8.5 Mechanical and electrical considerations.....	18
9 Galvanic anode manufacturing	18
9.1 Pre-production test.....	18
9.2 Coating.....	18
9.3 Anode core materials.....	19
9.4 Aluminium anode materials.....	19
9.5 Zinc anode materials.....	20
10 Galvanic anode quality control	20
10.1 General.....	20
10.2 Steel anode cores.....	20
10.3 Chemical analysis of anode alloy.....	21
10.4 Anode mass.....	21
10.5 Anode dimensions and straightness.....	21
10.6 Anode core dimensions and position.....	22
10.7 Anode surface irregularities.....	22
10.8 Cracks.....	22
10.9 Internal defects, destructive testing.....	23
10.10 Electrochemical quality control testing.....	24
11 Galvanic anode installation	25
12 Impressed-current CP systems	26
12.1 Current sources and control.....	26
12.2 Impressed-current anode materials.....	26
12.3 System design.....	26

12.4	Manufacturing and installation considerations.....	27
12.5	Mechanical and electrical considerations.....	27
13	Documentation.....	28
13.1	Design, manufacturing and installation documentation.....	28
13.2	Commissioning procedures.....	29
13.3	Operating and maintenance manual.....	29
14	Operation, monitoring and maintenance of CP systems.....	30
14.1	General.....	30
14.2	Monitoring plans.....	30
14.3	Repair.....	30
Annex A (normative) Galvanic anode CP design procedures.....		31
Annex B (normative) Attenuation of protection.....		37
Annex C (normative) Performance testing of galvanic anode materials.....		40
Annex D (normative) CP monitoring and surveys.....		42
Annex E (normative) Laboratory testing of galvanic anodes for quality control.....		49
Annex F (informative) Interference.....		51
Annex G (informative) Pipeline design for CP.....		53
Bibliography.....		59

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 15589-2 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*.

This second edition cancels and replaces the first edition (ISO 15589-2:2004), which has been technically revised as follows:

- In Clause 6 recommendations for isolating joints are included.
- In Clause 7 a subclause on hydrogen-induced stress cracking evaluation is included.
- In Clause 7 coating breakdown factors have been reorganized by splitting into “with” and “without” concrete coating. More conservative values for some coating systems have been selected based on feedback from daily practice in industry.
- In Clause 8 recommendations on anode electrochemical properties for seawater with low salinity are included.
- Design values for electrochemical capacity in Clause 8 have been reduced. Higher values are permitted if properly documented.
- Quality control of anodes has been adjusted regarding tolerances, straightness, mass, surface irregularities and cracking (Clause 10).
- The guidance on attenuation calculation has been significantly extended. A new Annex B has been introduced and includes several examples and alternative methods.
- Regarding anode testing, only free-running testing is accepted (see Annex C).

ISO 15589 consists of the following parts, under the general title *Petroleum, petrochemical and natural gas industries — Cathodic protection of pipeline transportation systems*:

- *Part 1: On-land pipelines*
- *Part 2: Offshore pipelines*

Introduction

The technical revision of this part of ISO 15589 has been carried out in order to accommodate the needs of industry and to move this International Standard to a higher level of service within the petroleum, petrochemical and natural gas industry.

Pipeline cathodic protection is achieved by the supply of sufficient direct current to the external pipe surface, so that the steel-to-electrolyte potential is lowered on all the surface to values at which external corrosion is reduced to an insignificant rate.

Cathodic protection is normally used in combination with a suitable protective coating system to protect the external surfaces of steel pipelines from corrosion.

Users of this part of ISO 15589 should be aware that further or differing requirements may be needed for individual applications. This part of ISO 15589 is not intended to prevent alternative equipment or engineering solutions from being used for individual applications. This may be particularly applicable where there is innovative or developing technology. Where an alternative is offered, it is intended that any variations from this part of ISO 15589 be identified and documented.

This part of ISO 15589 can also be used for offshore pipelines outside the petroleum, petrochemical and natural gas industries.

Petroleum, petrochemical and natural gas industries — Cathodic protection of pipeline transportation systems —

Part 2: Offshore pipelines

1 Scope

This part of ISO 15589 specifies requirements and gives recommendations for the pre-installation surveys, design, materials, equipment, fabrication, installation, commissioning, operation, inspection and maintenance of cathodic protection (CP) systems for offshore pipelines for the petroleum, petrochemical and natural gas industries as defined in ISO 13623.

This part of ISO 15589 is applicable to carbon steel, stainless steel and flexible pipelines in offshore service.

This part of ISO 15589 is applicable to retrofits, modifications and repairs made to existing pipeline systems.

This part of ISO 15589 is applicable to all types of seawater and seabed environments encountered in submerged conditions and on risers up to mean water level.

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.

ISO 1461, *Hot dip galvanized coatings on fabricated iron and steel articles — Specifications and test methods*

ISO 8044, *Corrosion of metals and alloys — Basic terms and definitions*

ISO 8501-1, *Preparation of steel substrates before application of paints and related products — Visual assessment of surface cleanliness — Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings*

ISO 9606-1, *Qualification testing of welders — Fusion welding — Part 1: Steels*

ISO 13623, *Petroleum and natural gas industries — Pipeline transportation systems*

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

ISO 15607, *Specification and qualification of welding procedures for metallic materials — General rules*

ASTM D1141¹⁾, *Standard Practice for the Preparation of Substitute Ocean Water*

AWS D1.1/D1.1M²⁾, *Structural Welding Code — Steel*

EN 10025 (all parts)³⁾, *Hot rolled products of structural steels*

EN 10204:2004, *Metallic products — Types of inspection documents*

1) American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA.

2) American Welding Society, 550 NW Le Jeune Road, Miami, FL 33126, USA.

3) European Committee for Standardization, Management Centre, Avenue Marnix 17, B-1000, Brussels, Belgium.

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 8044 and the following apply.

- 3.1 anode potential**
anode-to-electrolyte potential
- 3.2 anode sled**
anodes installed on a structure and connected to the pipeline by a cable
- 3.3 closed-circuit anode potential**
anode potential while electrically linked to the pipeline to be protected
- 3.4 coating breakdown factor**
 f_c
ratio of current density required to polarize a coated steel surface as compared to a bare steel surface
- 3.5 cold shut**
horizontal surface discontinuity caused by solidification of the meniscus of the partially cast anodes as a result of interrupted flow of the casting stream
- 3.6 driving voltage**
difference between the pipeline/electrolyte potential and the anode/electrolyte potential when the cathodic protection is operating
- 3.7 electric field gradient**
change in electrical potential per unit distance through a conductive medium, arising from the flow of electric current
- 3.8 electrochemical capacity**
 ϵ
total amount of electric charge that is produced when a fixed mass (usually 1 kg) of anode material is consumed electrochemically
- NOTE Electrochemical capacity is expressed in ampere hours.
- 3.9 final current density**
estimated current density at the end of the lifetime of the pipeline
- NOTE Final current density is expressed in amperes per square metre.
- 3.10 hydrogen-induced stress cracking**
HISC
cracking due to a combination of load and hydrogen embrittlement caused by the ingress of hydrogen formed at the steel surface due to the cathodic polarization

3.11**IR drop**

voltage due to any current, measured between two points of the metal of the pipe or two points of the electrolyte, such as seawater or seabed, in accordance with Ohm's law

NOTE IR drop and electric field gradient are related terms.

3.12**master reference electrode**

reference electrode, calibrated with the primary calibration reference electrode, used for verification of reference electrodes that are used for field or laboratory measurements

3.13**mean current density**

estimated average cathodic current density for the entire lifetime of the pipeline

NOTE Mean current density is expressed in amperes per square metre.

3.14**protection potential**

structure-to-electrolyte potential for which the metal corrosion rate is considered as insignificant

3.15**pitting resistance equivalent number****PREN**

number, developed to reflect and predict the pitting resistance of a stainless steel, based on the proportions of Cr, Mo, W and N in the chemical composition of the alloy

3.16**primary calibration reference electrode**

reference electrode used for calibration of master reference electrodes

3.17**remotely operated vehicle****ROV**

underwater vehicle operated remotely from a surface vessel or installation

[ISO 14723]

3.18**riser**

part of an offshore pipeline, including any subsea spool pieces, which extends from the seabed to the pipeline termination point on an offshore installation

[ISO 13623]

3.19**utilization factor** **μ**

fraction of the anodic material weight of a galvanic anode that can be consumed before the anode ceases to provide the minimum required current output

4 Symbols and abbreviated terms

4.1 Symbols

ε	electrochemical capacity
f_c	coating breakdown factor
μ	utilization factor

4.2 Abbreviated terms

CAT	cold-applied tape
CE	carbon equivalent
CP	cathodic protection
CRA	corrosion-resistant alloy
EPDM	ethylene propylene diene monomer
FBE	fusion-bonded epoxy
HISC	hydrogen-induced stress cracking
HSS	heat-shrinkable sleeve
PE	polyethylene
PP	polypropylene
PREN	pitting resistance equivalent number
PU	polyurethane
ROV	remotely operated vehicle
SCE	saturated calomel electrode
SMYS	specified minimum yield strength
SRB	sulphate reducing bacteria
3LPE	three-layer polyethylene
3LPP	three-layer polypropylene

5 General

5.1 Competence assurance

Personnel who undertake the design, supervision of installation, commissioning, supervision of operation, measurements, monitoring and supervision of maintenance of cathodic protection systems shall have the appropriate level of competence for the tasks undertaken.

NOTE 1 EN 15257 or the NACE Cathodic Protection Training and Certification Programme constitute suitable methods that can be used to assess competence of cathodic protection personnel.

NOTE 2 Competence of cathodic protection personnel to the appropriate level for tasks undertaken can be demonstrated by certification in accordance with prequalification procedures such as EN 15257, the NACE Cathodic Protection Training and Certification Programme or any other equivalent scheme.

5.2 Compliance

A quality system and an environmental management system should be applied to assist compliance with the requirements of this part of ISO 15589.

NOTE ISO/TS 29001 gives sector-specific guidance on quality management systems and ISO 14001 gives guidance on the selection and use of an environmental management system.

6 Cathodic protection system requirements

6.1 General

The CP system shall be designed to prevent external corrosion over the design life of the pipeline and to:

- provide sufficient current to the pipeline to be protected and distribute this current so that the selected criteria for CP are effectively attained on the entire surface;
- provide a design life of the anode system commensurate with the required life of the protected pipeline, or to provide for periodic rehabilitation of the anode system;
- provide adequate allowance for anticipated changes in current requirements with time;
- ensure that anodes are installed where the possibility of disturbance or damage is minimal;
- provide adequate monitoring facilities to test and evaluate the system's performance.

The CP system shall be designed with due regard to environmental conditions and neighbouring structures.

Offshore pipelines that are protected by galvanic anode systems should be electrically isolated from other pipelines and structures that are protected by impressed-current systems. Offshore pipelines shall be isolated from other unprotected or less protected structures, which could drain current from the pipeline's CP system. If isolation is not practical or stray current problems are suspected, electrical continuity should be ensured.

Care shall be taken to ensure that different CP systems of adjacent pipelines or structures are compatible and that no excessive current drains from one system into an adjacent system.

The pipeline CP design shall take into account the pipeline installation method, the types of pipeline and riser, and the burial and stabilization methods proposed. Further guidance is given in Annex G.

The CP system based on galvanic anodes shall be designed for the lifetime of the pipeline system using the calculation procedure given in Annex A.

For areas with high water velocities and areas with erosion effects (e.g. from entrained sand, silt, ice particles), the design of the CP system needs special attention and additional design criteria shall be considered.

Installation of permanent test facilities should be considered, taking into account specific parameters such as pipeline length, water depth and underwater access related to the burial conditions.

ISO 15589-1 should be used for the cathodic protection of short lengths of offshore pipelines and their branches that are directly connected to cathodically protected onshore pipelines.

6.2 Selection of CP systems

6.2.1 General

CP shall be achieved using either galvanic anodes or an impressed-current system. Galvanic anodes shall be connected to the pipe, either individually or in groups

NOTE 1 Galvanic anodes are limited in current output by the anode-to-pipe driving voltage and the electrolyte resistivity. Generally, anodes are attached directly to the pipe as bracelets. Sleds of anodes can also be placed at regular intervals along the pipeline.

NOTE 2 Some pipelines can be protected by anodes located at each end. Typically, this type of installation is used on inter-platform pipelines. Anodes for the pipeline can be attached to the platform if the pipeline is electrically connected to the platform.

Items that shall be considered in selecting the system to be used are covered in 6.2.2.

6.2.2 System selection considerations

Selection of the CP system shall be based on the following considerations:

- magnitude of the protective current required;
- resistivity of the seawater;
- availability and location of suitable power sources for impressed-current systems;
- existence of any stray currents causing significant potential fluctuations between pipeline and earth that can preclude the use of galvanic anodes;
- effects of any CP interference currents on adjacent structures that might limit the use of impressed-current CP systems;
- limitations on the space available, due to the proximity of foreign structures, and related construction and maintenance concerns;
- future development of the area and any anticipated future extensions to the pipeline system;
- cost of installation, operation and maintenance;
- reliability of the overall system;
- integrity of other pipelines and/or structures existing in the same area that could be affected by impressed-current systems unless proper measures are taken to prevent these effects.

NOTE Impressed-current systems can be preferred on short pipelines which terminate at platforms that have impressed-current systems installed or where an impressed-current system is operated from the shore. Impressed-current systems can also be preferred as a retrofit system on pipelines with galvanic anode failures, excessive anode consumption, operation beyond original design life or excessive coating deterioration. Impressed current can also be the preferred method for high-resistivity water.

6.3 Isolating joints

Isolating joints should be considered at the following locations:

- at connections to onshore pipelines or onshore receiving facilities;

- at connections to pipelines that require different protection criteria;
- between cathodically protected pipelines and non-protected facilities or less protected facilities;
- between pipeline systems (or structures) protected by impressed current and galvanic anodes.

If isolating joints are used they shall be designed and installed to ensure long-term integrity and shall be positioned to allow easy access for inspection and maintenance. Detailed design requirements are given in ISO 15589-1.

7 Design parameters

7.1 General

The design of a pipeline CP system shall be based on:

- detailed information on the pipeline to be protected, including material, length, wall thickness, outside diameter, pipe-laying procedures, route, laying conditions on the sea bottom, temperature profile (operating and shut in) along its whole length, type and thickness of corrosion-protective coating(s) for pipes and fittings, presence, type and thickness of thermal insulation, mechanical protection and/or weight coating;
- environmental conditions, including diurnal and seasonal variations, such as seawater salinity, temperature and resistivity, tides and seabed resistivity along the whole length of the pipeline;
- burial status (extent of backfilling after trenching or natural burial) and soil resistivity;
- design life of the system;
- information on existing pipelines in close proximity to or crossing the new pipeline, including location, ownership and corrosion-control practices;
- information on existing CP systems (platforms, landfalls, subsea structures, etc.) and electrical pipeline isolation;
- availability of electrical power, electrical isolating devices, electrical bonds;
- applicable local legislation;
- construction dates, start-up date (required for hot lines);
- presence of fittings, J-tubes, risers, clamps, wyes, tees and other appurtenances; and
- performance data on CP systems in the same environment.

If CP performance data for similar environments is not available (for example when moving into deeper water), data on the seawater characteristics (dissolved oxygen, salinity, pH, sea currents, and fouling) shall be obtained as these can affect cathodic polarization and calcareous deposit formation. For these situations, the required information shall be obtained from field surveys and/or corrosion test data including the following:

- protective current requirements to meet applicable criteria;
- electrical resistivity of the electrolyte, including seasonal changes if relevant;
- pipe burial depth (if buried) and identification of exposed span lengths and locations;
- water temperature at the seabed;
- oxygen concentration at the seabed;
- water flow rate at the seabed, including seasonal changes if relevant;

- seabed topography.

When reviewing operating experience, the following additional data should be considered:

- electrical continuity;
- electrical isolation;
- external coating integrity;
- deviation from specifications;
- maintenance and operating data.

Design procedures for the CP based on galvanic anode systems shall be in accordance with Annex A.

7.2 Protection potentials

7.2.1 Potential criteria

To ensure that adequate CP of a pipeline is being achieved, the measured potential shall be in accordance with Table 1.

NOTE 1 The effectiveness of CP or other external corrosion-control measures can be confirmed by direct measurement of the pipeline potential. However, visual observations of progressive coating deterioration and/or corrosion, for example, are indicators of possible inadequate protection. Physical measurements of a loss of pipe wall thickness, using divers, or using internal inspection devices such as intelligent pigs, can also indicate deficiencies in the level of corrosion protection.

Table 1 — Potential criteria

Materials	Minimum negative potential V	Maximum negative potential ^a V
Carbon steels		
Immersed in seawater	- 0,80	- 1,10 ^b
Buried in sediments	- 0,90 ^f	- 1,10 ^b
Austenitic stainless steels^g		
PREN ≥ 40 ^c	- 0,30 ^d	- 1,10
PREN < 40 ^c	- 0,50 ^d	- 1,10
Duplex stainless steels	- 0,50 ^d	e
Martensitic stainless (13 % Cr) steels	- 0,50 ^d	e

The potentials are referenced to an SCE reference electrode, which are equivalent to a silver/silver chloride reference electrode (Ag/AgCl/seawater) in 30 Ω·cm seawater.

^a These negative limits also ensure negligible impact of CP on pipeline coatings.

^b Where pipeline systems are fabricated from high-strength steel (SMYS > 550 MPa), the most negative potential that can be tolerated without causing hydrogen embrittlement shall be ascertained.

^c $PREN = \%Cr + 3,3 \% (Mo + 0,5W) + 16 \%N$.

^d For stainless steels, the minimum negative potentials apply for aerobic and anaerobic conditions.

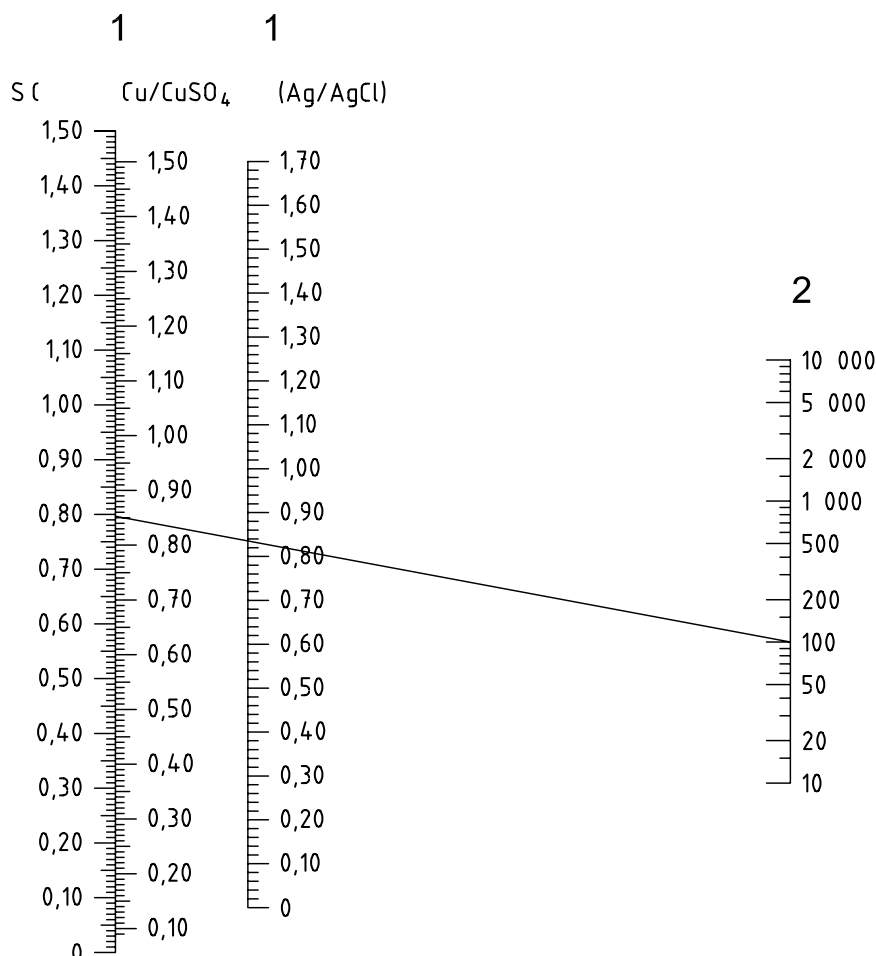
^e Depending on the strength, specific metallurgical condition and stress level encountered in service, these alloys can be susceptible to hydrogen embrittlement and cracking. If a risk of hydrogen embrittlement exists, then potentials more negative than -0,8 V should be avoided. See also 7.2.3.

^f This covers the possibility of SRB activity and/or high pipeline temperature ($T > 60^{\circ}C$).

^g If a metallurgical structure is not fully austenitic, these stainless steels can be susceptible to hydrogen-induced stress cracking (HISC) and high negative potentials should be avoided.

The potential of the Ag/AgCl/seawater reference electrode is dependent upon the concentration of chloride ions in the electrolyte, and hence the seawater resistivity. If the chloride concentration and hence the resistivity is known to differ significantly from that of ordinary seawater (typically 3,5 % and 30 Ω·cm respectively), the protection potential criteria shall be adjusted in accordance with Figure 1.

NOTE 2 The term “Ag/AgCl/seawater (undersaturated) reference electrode” can be used for this electrode.



Key

- 1 potential, in volts
- 2 resistivity, in Ω·cm

Figure 1 — Nomogram for the correction of potential readings made with the Ag/AgCl/seawater electrode in waters of varying resistivity against the SCE and Cu/CuSO₄ reference electrodes^[17]

EXAMPLE If brackish water of 100 Ω·cm resistivity exists at the pipeline potential measurement site, the least negative potential for the effective corrosion-protection electrode will be -0,84 V and not -0,80 V as given in Table 1, with reference to the Ag/AgCl/seawater reference electrode.

Alternative reference electrodes for specific conditions are given in D.3.2.

7.2.2 HISC evaluation for martensitic and duplex stainless steel materials

HISC is a non-ductile mode of failure caused by an interaction between stresses, the cathodic protection system and a susceptible material. A special assessment shall be carried out to ensure that the risk of HISC is minimized. All load contributions causing stress and strain shall be included.

For duplex stainless steels, DNV-RP-F112^[8] may be used to assess acceptable stresses and strains.

Fillet welds, doubler plates or aluminothermic welds should not be used directly on high-strength carbon steels (SMYS > 550 MPa), martensitic or duplex stainless steel materials. Installation of galvanic anode cables should be performed to special pipejoints consisting of internally clad carbon steel or other CRA materials which are not susceptible to HISC.

7.2.3 Thermally sprayed aluminium

If a component with thermally sprayed aluminium is cathodically protected at potentials more negative than $-1,15$ V, the thermally sprayed aluminium can suffer corrosion as a consequence of the build-up of alkali at the metal/electrolyte interface. A polarized potential more negative than $-1,15$ V should not be used unless previous test results or operating experience indicate that no significant corrosion will occur.

7.3 Design life

The design life of the pipeline CP system shall cover the period from initial installation to the end of pipeline operation as a minimum. However, the possibility of future life extension or future pipeline connections should be recognized at the design stage. Provisions should be made to accommodate possible future events and this can include revised coating breakdown criteria and/or incorporating facilities for future anode retrofits.

7.4 Design current densities for bare steel

7.4.1 General

The design current densities depend upon the seawater temperature, the oxygen content, the seawater velocity and the ability to build up protective calcareous films on bare metal surfaces.

NOTE 1 In theory, three values of current density are significant: the initial, mean and final current densities, which refer to the current density required to polarize the pipeline within a reasonable period of time (i.e. 1 to 2 months, initial), the current density necessary to maintain the polarization (mean), and the current density necessary for an eventual repolarization which may occur close to the end of the pipeline life (final), e.g. after a heavy storm. For a coated pipeline, the initial current density is never the critical constraint in the design, so it is not considered further in Annex A. Pipelines are located on the seabed and depolarization in storms has not been found to have a significant effect, so the same current density value can be used for the mean and final current densities.

If it is decided for a specific location that a higher final current density needs to be considered in the design because of storms, a value which is 20 mA/m² above the mean value for that temperature may be used.

For most applications in water depth of less than 500 m, the design current densities are dependent only on the seawater temperature, and the current densities for non-buried pipelines should be assessed from Figure 2.

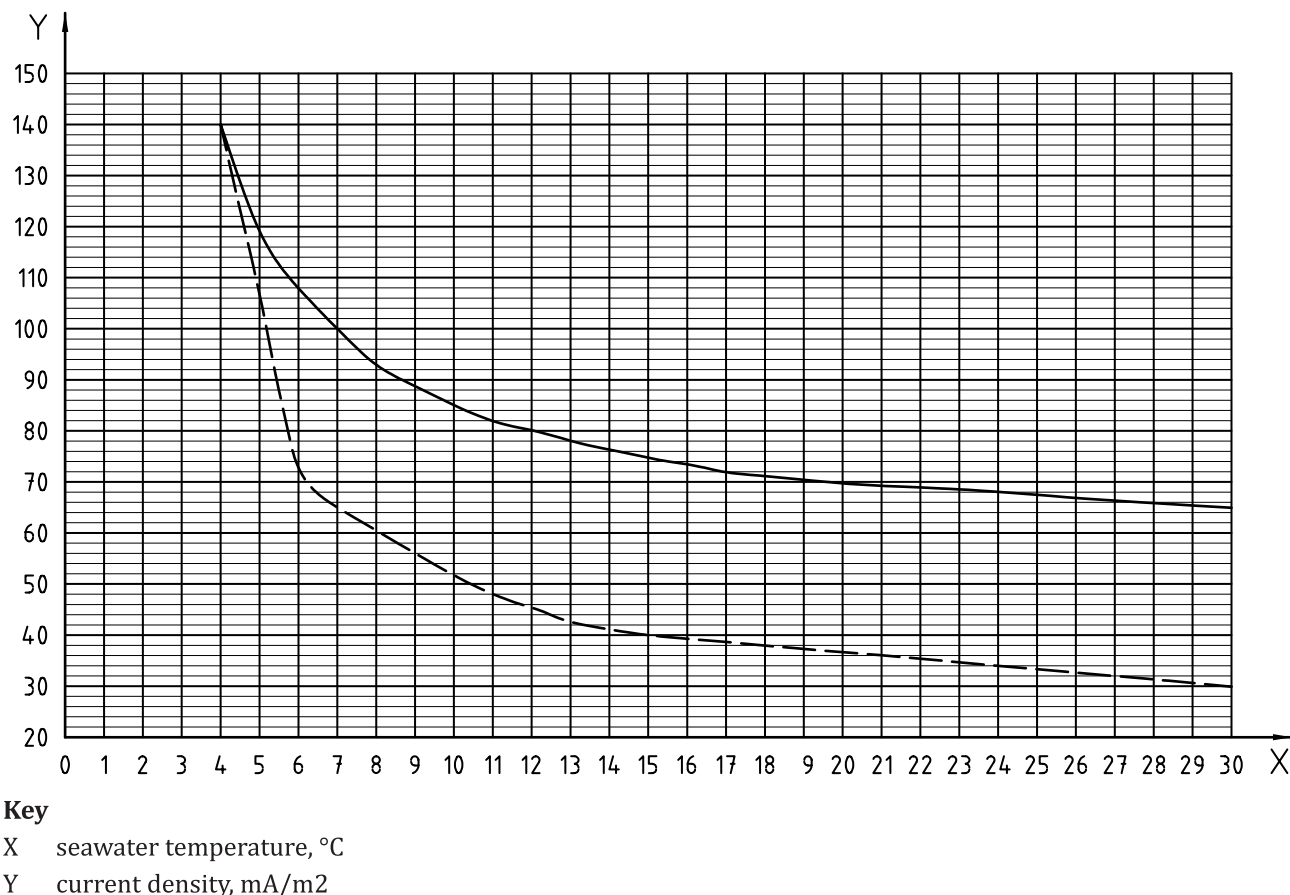


Figure 2 — Mean current density range for non-buried bare steel pipelines

In Figure 2, the lower current-density curve may be used where there are no significant changes in oxygen content from surface to seabed, no build-up of protective calcareous films, and low to moderate seabed currents (up to 2 knots).

If no other data are known, the upper curve in Figure 2 should be used.

NOTE 2 Calcareous deposits, formed on the exposed surfaces of the pipeline by the application of CP current, reduce the current density required to maintain protective potentials and also improve current distribution. Pipeline coatings also favour the formation of a dense calcareous deposit, because the initial current density is rather high when defects are formed in the coating. However, the solubility of potential film-forming calcareous deposits is dependent on temperature, and colder waters might not allow the formation of protective calcareous deposits, or could require higher initial current density to achieve polarization.

NOTE 3 The lower curve was published in Reference [19]. This curve is based on test and field data from many platform and pipeline locations world-wide, collected over a number of years. The upper curve is a conservative curve fit of the data published in References [7] and [11] and, especially for deep waters, is generally accepted by operators and represents the highest current density values reported normally for seawater saturated with oxygen. The required current density values for a given field lie somewhere between these two extremes.

At temperatures below 6 °C, the mean design current density shall be 120 mA/m², unless otherwise specified, as limited data are available for temperatures below 6 °C.

If the seawater temperature profile along the pipeline route is not known, the required current density shall be based upon the minimum seabed temperature measured, which is usually the temperature at the deepest location along the pipeline route.

If the seawater temperature profile along the pipeline route is known, the curves in Figure 2 should be used with the averaged seawater temperatures to obtain current densities for each pipeline section. If the annual average seawater temperature varies by more than 5 °C over the pipeline length, the pipeline

length should be split up into separate sections that cover intervals of no more than 5 °C each. The averaged seawater temperature should be used for each section. The design current densities discussed above are applicable for CP of bare carbon steel and stainless steel (austenitic, martensitic and duplex).

Current densities may alternatively be based on field measurements or data from facilities installed in the same general geographical location.

EXAMPLE There are specific locations where higher and lower current densities have been reported. These have been related to significant changes in oxygen content with depth, and/or significant seabed currents (see Table 2).

Table 2 — Examples of design current densities for specific locations

Location	Water depth m	Seawater temperature °C	Mean current density mA/M ²	Comment
US West Coast	> 500	10 to 12	90	moderate current flow
Cook Inlet	all depths	2	380	high seabed currents
Australia	> 500	12 to 18	90	large seasonal temperature variation
Norwegian Sea	> 1 000	-1 to 4	200	cold deep conditions
Offshore Brazil	> 300		130	temperature to be considered

7.4.2 Splash zone

For risers in the splash zone, current densities selected shall be 10 mA/m² higher than for the equivalent riser or pipeline below the splash zone (at the same temperature).

NOTE Splash zone depths vary by location; for example, in the North Sea, splash zones typically extend down to -10 m, whereas in the South China Sea, the splash zones typically extends down to -1 m.

7.4.3 Buried pipelines

For pipelines fully buried in sediments (trenched and naturally buried) or artificially covered (e.g. rock dumping), a design current density (mean and final) of 20 mA/m² should be used, irrespective of seawater temperature, oxygen content or depth.

7.4.4 Elevated temperatures

Pipelines operating with temperatures in excess of 25 °C on the outside metallic surface of the pipe require an adjustment to the design current density. The design current densities shall be increased by 1 mA/m² for each degree Celsius of the metal/environment above 25 °C up to 100 °C.

NOTE Increasing water temperature decreases oxygen solubility. Increasing temperatures also accelerate the corrosion rate.

7.4.5 Current drains

If subsea facilities are connected to the pipeline CP system, the current drain to subsea structures, wellheads, manifolds and well casing shall be included in the design. An allowance should be included in the total design current requirements to compensate for the current load imposed by the well casings below the mudline. The design current for wells should be 5 A per well.

7.5 Coating breakdown factors

The current demand of a coated pipeline increases with time as the coating deteriorates. Enough cathodic protection capacity should be provided to maintain protection as the coating deteriorates.

These coating breakdown factors shall be applied to calculate the bare metal surface areas of the coated pipe for mean conditions and at the end of the design life respectively (see Annex A). Mean and final coating breakdown factors shall be calculated as follows.

The mean coating breakdown factor, \bar{f}_c , is given by Equation (1):

$$\bar{f}_c = f_i + (0,5\Delta f \times t_{dl}) \quad (1)$$

The final coating breakdown factor, f_f , is given by Equation (2):

$$f_f = f_i + (\Delta f \times t_{dl}) \quad (2)$$

where

f_i is the initial coating breakdown factor at the start of pipeline operation;

Δf is the average yearly increase in the coating breakdown factor;

t_{dl} is the design life, expressed in years.

The coating breakdown factors given in Tables 3 and 4 should be considered. Coating breakdown factors for pipeline coatings not included in Tables 3 and 4 shall be fully documented.

NOTE 1 Typical parameters f_i and Δf are given in Table 3 (for pipelines without concrete weight coating) and Table 4 (for pipelines with concrete weight coating) which address combinations of the most common coating systems used for corrosion prevention or thermal insulation. The coating breakdown factors given refer to both seawater exposed pipelines and pipelines buried in the seabed.

NOTE 2 The coating breakdown factors are based on coating quality being in accordance with the various parts of ISO 21809^[4] or with other commonly applied industry standards specifying an equal level of quality coatings. The coating breakdown factors include some allowance for damage to pipeline coatings during fabrication, handling, transportation, installation or operation such as third-party damage (e.g. anchors, trawl gear). However, they do not include allowance for extreme damage or for field joints intentionally left uncoated.

If extreme damage or uncoated field joints are anticipated, the affected surface area shall be estimated and included in design calculations as bare metal surface ($f_c = 1$), or increase the coating breakdown factors in Tables 3 and 4.

Table 3 — Coating breakdown factors, f_c , for pipelines without concrete weight coating

Factory-applied coating type	Field joint coating type	f_i	Δf
Fusion-bonded epoxy (FBE)	Heat-shrinkable sleeves (HSS ^a)	0,080	0,003 5
	FBE	0,060	0,003 0
Three-layer coating systems including epoxy, adhesive and polyethylene (3LPE)	HSS ^a	0,009	0,000 6
	FBE	0,008	0,005
	Multilayer coating including epoxy and PE (e.g. moulded, HSS ^a or flame spray)	0,007	0,000 5
Three-layer coating systems including epoxy, adhesive and polypropylene (3LPP)	HSS ^a	0,007	0,000 3
	FBE	0,006	0,000 2
	Multilayer coating including epoxy and PP (e.g. HSS ^a , hot tapes, moulding or flame spray)	0,005	0,000 2
Heat insulation multilayer coating systems including epoxy, adhesive and/or PE, PP or PU	Thick multilayer coating systems including epoxy, adhesive and/or PE, PP, PU, HSS ^a or a combination of these products.	0,002	0,000 1
Thick coatings: elastomeric materials (e.g. polychloroprene or EPDM) or glassfibre-reinforced resins	Thick elastomeric materials or glassfibre-reinforced resins	0,002	0,000 1
Flexible pipelines	Not applicable (mechanical couplings)	0,002	0,000 1
^a HSS can be used with or without primer.			

Table 4 — Coating breakdown factors, f_c , for pipelines with concrete weight coating

Factory-applied coating type	Field joint infill	Field joint coating type	f_i	Δf
Asphalt or coal tar enamel	no	Cold-applied tapes (CAT ^a) or heat-shrinkable sleeves (HSS) over a wire-brushed surface to St 3	0,045	0,002 5
		Cold-applied tapes (CAT ^a) or heat-shrinkable sleeves (HSS) over a blast-cleaned surface to Sa 2 ½	0,040	0,002 0
	yes	CAT ^a	0,030	0,001 5
		HSS	0,020	0,000 8
Fusion bonded epoxy (FBE)	no	HSS	0,045	0,002 5
		FBE	0,035	0,002 0
	yes	HSS	0,040	0,002 0
		FBE	0,030	0,001 5
Three-layer coating systems including epoxy, adhesive and polyethylene (3LPE)	no	HSS or FBE,	0,008	0,005
		Multilayer coating including epoxy and PE (e.g. HSS, or flame spray)	0,007	0,000 3
	yes	HSS or FBE	0,004	0,000 2
		Multilayer coating including epoxy and PE (e.g. HSS or flame spray)	0,004	0,000 2
Three-layer coating systems including epoxy, adhesive and polypropylene (3LPP)	no	HSS or FBE	0,008	0,000 5
		Multilayer coating including epoxy and PP (e.g. HSS, moulded or flame spray)	0,007	0,000 3
	yes	HSS or FBE	0,004	0,000 2
		Multilayer coating including epoxy and PP (e.g. HSS, moulded or flame spray)	0,004	0,000 2

^a CAT should be applied with primer.

For heat insulation covered with concrete coating, the values for heat insulation in Table 3 should be used.

8 Galvanic anodes

8.1 Design of system

The galvanic anode system shall be designed by locating properly shaped and sized anodes along the pipeline such that sufficient current is delivered to the pipeline to maintain the required potentials throughout the design life.

NOTE 1 Normally, the CP system consists of bracelet anodes distributed at regular intervals along the pipeline.

Design calculations for the CP systems shall demonstrate that the anodes give the pipeline the necessary current to meet the current density requirements. The anodes shall deliver sufficient current to meet the mean and final design current demands.

NOTE 2 The weight and shape of individual anodes can be limited by anode manufacturing and handling constraints.

If anode sleds are used, alternative methods for distribution and connection to the pipeline should be considered.

The spacing between anodes shall be determined together with the number of anodes. The anode spacing shall be close enough to maintain an adequate protection in the event of mechanical or electrical loss of a single anode. When accepted by the pipeline operator, anode spacing exceeding 300 m shall be justified

by attenuation calculations in accordance with Annex B or other mathematical modelling accepted by the pipeline operator.

For short pipelines, anodes may be installed at each end of the pipeline if it can be demonstrated by mathematical calculations or modelling that CP can be achieved. Typically, this type of installation is used on inter-platform pipelines. Anodes for the pipeline can be attached to the platform if the pipeline is electrically connected to the platform. Attenuation calculations shall be carried out in accordance with Annex B for these installations to determine whether it is feasible to protect the mid-point of the pipeline using anodes located at the ends.

Extra anodes should be placed on the portion of the pipeline that is near a structure, platform or shore approach. A factor of 2 should be included in the calculated design current demand for the first 1 000 m.

NOTE 3 The reasons for adding extra anodes include:

- increased risk of pipeline coating damage due to dropped objects and vessel anchors;
- possibility of an increased current drain;
- likelihood that the pipeline potential is more negative than that on the platform, so that the pipeline anodes near the structure will also provide current to the platform.

All these factors increase current output from the anodes and reduce anode life.

Anodes and anode supports shall be designed to avoid any sharp edges or corners or protruding assemblies which may be hazardous to personnel (see also Annex F). This latter requirement particularly applies to diving operations conducted near anode installations.

NOTE 4 Further information on galvanic anodes is given in EN 12496^[9].

8.2 Selection of anode material

The alloy selected shall be one that has given a satisfactory performance under similar field conditions, or in laboratory and field trials in a simulated environment.

Unless otherwise documented, aluminium anodes should not be used below 0,5 % salinity.

Zinc anodes should not be used at temperatures exceeding 50 °C unless their performance is supported by appropriate test data to the contrary.

Intergranular corrosion and/or a reduction in electrochemical capacity are the main problems for zinc anodes at elevated temperatures. The galvanic anode alloys developed for marine applications have been specifically conceived to perform in seawater with an alkaline pH, high salinity and a significant content of oxygen. For some areas, the seawater and mud conditions can be very different, such as being totally anaerobic with large concentrations of SRBs and sulphides. In addition, the salinities can be low. This may be of importance for anode selection. Long-term testing in accordance with Annex C should be carried out for applications in such environments.

NOTE 1 Aluminium and zinc alloys are the materials most often used as galvanic anodes on pipelines. Typical compositions are respectively given in 9.4 and 9.5.

NOTE 2 Aluminium alloy anodes have decreased electrochemical efficiency at elevated temperatures. Certain aluminium alloy compositions can be unsuitable at elevated temperatures.

NOTE 3 The behaviour of certain aluminium alloys can be adversely affected by burial in seabed mud, particularly if the current output remains low.

NOTE 4 Aluminium alloys containing magnesium can suffer ageing with a loss of mechanical properties.

8.3 Electrochemical properties

For design purposes, the values quoted in Table 5 should be used. Alternative values for the electrochemical capacities of galvanic anodes may be used if the data are properly documented by testing as detailed in Annex C. The electrochemical properties shall be documented for the relevant anode operating temperatures.

Table 5 — Design values for galvanic anodes

Anode type	Anode surface temperature ^a	Immersed in seawater		Buried in seawater sediments ^d	
		Potential	Electrochemical capacity	Potential	Electrochemical capacity
		Ag/AgCl/seawater	ϵ	Ag/AgCl/seawater	ϵ
	°C	mV	A·h/kg	mV	A·h/kg
Aluminium	< 30	- 1 050	2 000	- 1 000	1 500
	60	- 1 050	1 500	- 1 000	800
	80 ^b	- 1 000	900	- 1 000	400
Zinc	< 30	- 1 030	780	- 980	750
	> 30 to 50 ^c			- 980	580

Electrochemical capacity for a given alloy is a function of temperature and anode current density. Reference is made to Annex A for guidance on CP design for variations in anode current densities.

For non-buried pipelines, the anode surface temperature should be taken as the external pipeline temperature and not the internal fluid temperature. For buried pipelines, the anode surface temperature shall be taken as the internal fluid temperature.

^a For anode surface temperatures between the limits stated, the electrochemical capacity shall be interpolated.

^b For aluminium anodes, the anode surface temperature shall not exceed 80 °C unless the performance has been demonstrated in tests and has been documented.

^c For zinc anodes, the anode surface temperature shall not exceed 50 °C unless satisfactory performance has been demonstrated in tests and has been documented.

^d Pipelines which are rock-dumped shall be considered as buried in seawater sediments.

The design values in Table 5 are applicable to seawater with a typical salinity of 3,5 %. For salinities below 1,2 %, the design values given for anodes buried in sediments should be used.

NOTE 1 The electrochemical capacity can be lower for aluminium in brackish water than in ocean seawater.

For pipelines where the burial condition is unknown or the pipeline is expected to be marginally covered with loose sediments, the cathodic protection design should be made on the basis of

- a) buried anodes, which will give the lowest anode capacity (due to high surface temperature), and
- b) pipeline exposed to seawater, which will give the highest current requirement.

NOTE 2 Anode compositions which have been qualified for one set of operating conditions, e.g. low temperature, unburied, might not be suitable for use under other conditions, e.g. high temperature, buried.

8.4 Anode shape and utilization factor

Anodes shall be designed (see 8.5) in such a way that a utilization factor, μ , is assured. Unless otherwise specified, a utilization factor of 0,80 should be used for bracelet anodes and a minimum of 0,90 for slender anode systems.

The distribution of the anode insert within the body of the anode material should be considered to ensure that the specified utilization factors are achieved.

For bracelet anodes with a thickness of less than 50 mm, utilization factors of less than 0,80 may be used depending on the details and tolerances of the anode insert. Reduced anode surface area and possible insert exposure shall be considered.

8.5 Mechanical and electrical considerations

The internal diameter of a bracelet anode should be determined by the diameter of the pipe and the thickness of coatings applied. Tolerances of the outer diameter of pipe and coating thickness shall be taken into account.

Depending on the pipeline installation method, the anodes can be susceptible to damage. This concern is critical when the anodes pass over a stinger as the pipeline leaves the lay barge.

For non-weight-coated pipelines, anodes with either tapered shoulders or taper cones should be used to reduce the risk of the anodes catching on the stinger rollers.

For weight-coated pipelines, the thickness of anodes should match the thickness of the weight coating, such that the anodes will roll smoothly over the stinger rollers.

NOTE A variety of galvanic anode designs are available for attachment to the pipeline. Semi-cylindrical bracelets with tapered and square shoulders are available for use on small- and medium-diameter pipelines. For larger-diameter pipelines where semi-cylindrical anodes would be impractical, segmented designs are available. For special circumstances, anodes can sometimes be cast directly onto the pipe.

The core shall be designed to maintain electrical integrity with the anode body for the full design life of the anode.

The electrical connection between the pipeline and the anode is generally made by a bonding wire or direct welding of the anode core to the pipeline. The bonding wire can be attached by a variety of methods, including aluminothermic welding and pin brazing. The attachment method shall be compatible with the requirements of the pipe lay method and the metallurgy of the pipeline steel (see 7.2.2).

Anode core extensions of bracelet half-shells are generally oriented in the longitudinal direction of the half-shell and at the mid-point of the half-shell cross-section. Anode core extensions, usually a flat steel bar, should be fully welded to the core and the dimensions should be compatible with the pipe dimensions and material.

9 Galvanic anode manufacturing

9.1 Pre-production test

The detailed anode design shall include anode drawings showing shape and dimensions with tolerances. Prior to fabrication of the anodes, a pre-production test shall be carried out at the foundry to ascertain that all moulds, cores, casting equipment and other components are in accordance with applicable standards, governing drawings, dimensions, tolerances, inspection procedures and data sheets.

At least one of the anode cast assemblies should be inspected destructively in accordance with 10.9.

Other types of procedure qualification may be considered.

9.2 Coating

Bracelet anodes should be coated on the sides facing the pipeline and the concrete weight coating. The coating applied to the anode faces should be an immersion-grade two-component epoxy with a minimum thickness of 100 µm. Coating sides of other anode types should also be considered.

The exposed (external) surface of the anode shall be free from coating.

9.3 Anode core materials

Anode cores shall be fabricated from weldable structural steel plate/sections according to a recognized standard such as EN 10025 or similar. Anode core materials to be welded to the pipeline shall be compatible with the pipeline material or structural elements to which it is attached, and the carbon equivalent (CE) shall not exceed the CE value of the pipeline material. The CE value shall be calculated using Equation (3).

$$CE = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15 \quad (3)$$

where the symbols of the elements represent the mass fraction of the corresponding element.

NOTE The formatting for Equation (3) does not conform to the standard ISO formatting but it has been accepted, exceptionally, on the basis of its long-standing and well established history in the industry.

If the full chemical composition is not reported, the alternative CE value of Equation (4) may be used.

$$CE = C + Mn/6 + 0,04 \quad (4)$$

The material certificate for the anode cores shall meet the requirements of EN 10204:2004, 2.1 b).

All fabrication welding of steel anode cores shall be in accordance with the relevant requirements of AWS D1.1/D1.1M or an equivalent standard, and performed by welders qualified according to ISO 9606-1 or AWS D1.1/D1.1M. Qualification of welding procedures shall be in accordance with the requirements of ISO 15607, AWS D1.1/D1.1M, or equivalent.

Anode core steel for aluminium anodes shall be blast-cleaned to Sa 2½ in accordance with ISO 8501-1 prior to casting and maintained until casting commences.

Anode core steel for zinc anodes shall be blast-cleaned to the minimum standard Sa 2½ in accordance with ISO 8501-1 or galvanized according to ISO 1461 or equivalent. Rust discoloration and/or visual surface contamination of zinc-coated surfaces shall not be permitted. The degree of cleanliness shall be maintained until casting.

9.4 Aluminium anode materials

The aluminium anode material should be of the Al-Zn-In type. The chemical composition of the anodes shall be formulated to meet the potential and electrochemical capacity requirements of the project design. A typical chemical composition known to perform well in many conditions is given in Table 6. This composition is in accordance with EN 12496. Other compositions may be used if testing demonstrates that they meet the required anode electrochemical properties. Caution should be exercised if any element falls outside the specified range, since the anode electrochemical properties may be less than the design requires.

Table 6 — Typical chemical composition of aluminium anode materials

Element ^a	Mass fraction <i>w</i>	
	min. %	max. %
Zn	2,5	5,75
In	0,016	0,040
Fe	—	0,09
Si	—	0,12
Cu	—	0,003
Cd	—	0,002
Other	—	0,02 (each)
Al	Remainder	

^a Under certain operating conditions such as deep (>500 m) or cold water, it can be necessary to select a narrower anode composition range than given in this table in order to obtain the required anode electrochemical properties.

9.5 Zinc anode materials

A typical chemical composition known to perform well in many conditions is given in Table 7.

Table 7 — Typical chemical composition of zinc anode materials

Element	Mass fraction <i>w</i>	
	min. %	max. %
Cu	—	0,005
Al	0,10	0,50
Fe	—	0,005
Cd	0,025	0,07
Pb	—	0,006
Zn	Remainder	

Other compositions may be used if testing demonstrates that they meet the required anode electrochemical properties. EN 12496 gives alternative compositions for zinc anodes. Caution should be exercised when any element falls outside the specified range, as anode performance may be less than the design requires.

10 Galvanic anode quality control

10.1 General

A quality control procedure shall be followed to ensure that the requirements in this clause are met.

10.2 Steel anode cores

All welds shall be visually inspected.

Required surface finish shall be verified by visual inspection immediately prior to casting.

10.3 Chemical analysis of anode alloy

Two samples from each heat shall be taken for chemical analysis. The samples shall be taken in the beginning and at the end of casting from the pouring stream. For smaller alloying furnaces (max. 500 kg), it is acceptable to take one sample per heat. The sample shall be taken at the beginning of the first heat and at the end of the second heat, then in the beginning of the third heat and so on. The samples shall be analysed to verify the required chemical composition.

Anodes from heats whose chemical composition do not meet the required chemical composition shall be rejected.

10.4 Anode mass

Individual anode castings of each type shall have a net mass within $\pm 3\%$ of the nominal net mass for anode castings with total mass above 50 kg. For anode castings below 50 kg, the mass tolerances shall be $\pm 5\%$ unless otherwise agreed between the end user and the relevant parties.

At least 10 % of the total number of anode castings shall be weighed to confirm compliance with this requirement. If agreed between the end user and the relevant parties, the weighing can be done in groups, which gives an average individual weight.

The total net mass of anodes shall not be less than the nominal value. A maximum value can be agreed between between the end user and the relevant parties.

10.5 Anode dimensions and straightness

10.5.1 Slender anodes

The anode dimensions and straightness for slender anodes shall conform to the following:

- anode length shall be within $\pm 3\%$ of the nominal length or ± 25 mm, whichever is smaller;
- anode mean width shall be within $\pm 5\%$ of the nominal mean width;
- anode depth shall be within $\pm 10\%$ of the nominal mean depth;
- the diameter of cylindrical anodes shall be within $\pm 5\%$ of the nominal diameter;
- the straightness of the anode shall not deviate by more than 2 % of the anode nominal length from the longitudinal axis of the anode.

At least 10 % of the total number of anodes shall be checked to confirm compliance with these requirements.

10.5.2 Bracelet anodes

Each bracelet anode length shall be within $\pm 3\%$ of the nominal length or ± 25 mm, whichever is smaller.

The anode internal diameter shall conform to the following dimensional tolerances:

0 / +4 mm for pipeline diameters	≤ 300 mm
0 / +6 mm for pipeline diameters	> 300 mm and ≤ 610 mm
0 / +1% for pipeline diameters	> 610 mm

The dimensional tolerance on the anode thickness shall be ± 3 mm.

At least 10 % of the total number of anodes shall be checked to confirm compliance with these requirements.

Anodes shall be free from excessive bowing or twisting. The anode casting shall not deviate by more than 2 % of the anode nominal axial length from the longitudinal axis of the anode. At least one completely assembled bracelet anode shall be fitted. This shall be verified by fitting an agreed number of bracelet assemblies to a full-length former or by an equivalent method. The external diameter shall not exceed the summation of tolerances given above.

10.6 Anode core dimensions and position

Tolerances on the anode core position within the anode shall be subject to agreement prior to fabrication, to comply with utilization factor requirements, and should be part of the fabrication quality plan. Anode core protrusions and any other critical dimensions shall be measured and shall conform to specified requirements.

10.7 Anode surface irregularities

10.7.1 Slender anodes

Slender anodes shall be inspected visually to confirm compliance with the following requirements:

- shrinkage depressions shall not exceed 10 % of the nominal depth of the anode material to the anode core, as measured from the plane of the anode surface to the bottom of the depression;
- in the topping-up area, the maximum shrinkage shall not be more than a 10 mm depth measured from a straight edge across the topping-up face and not more than 0,5 % of the gross anode volume; any additional topping-up materials or casting surface irregularities shall be fully bonded to the bulk anode material;
- cold shuts shall not exceed a depth of 10 mm and/or extend over a total length of more than three times the width of the anode;
- all protrusions that are hazardous to personnel during handling shall be removed.

10.7.2 Bracelet anodes

Bracelet anodes shall be inspected visually to confirm compliance with the following requirements:

- shrinkage depressions shall be < 10 % of the thickness of the anode as measured from the uppermost corner to the bottom of the depression. Shrinkage depressions that expose the anode core are not acceptable;
- in the topping-up area, the maximum shrinkage shall not be more than 10 mm measured from a straight edge across the topping-up face and not more than 0,5 % of the gross anode volume. Any additional topping-up materials or casting surface irregularities shall be fully bonded to the anode material;
- any cold shuts shall be < 10 mm depth and/or extend over a total length of < 150 mm;
- all protrusions that are hazardous to personnel during handling of the anode(s) shall be removed.

10.8 Cracks

10.8.1 General

All anodes shall be inspected for cracks.

NOTE Cracks can occur while cooling during the casting of galvanic anode bracelets because of the different coefficients of expansion of the anode and the core. These cracks are not detrimental, provided they do not converge in a manner that allows loss of anode material.

No treatment shall be applied to grind, peen, or in any other manner dress cracks before inspection and checks.

Zinc anodes shall be free from visible cracking without the aid of magnification.

Cracks may be accepted in aluminium anodes provided the cracks will not cause any mechanical failure during installation, transportation or service of the anode. The combination of cracks and lack of bond to the anode core and cracks in the area where the anodes are not fully supported by the anode core shall not be accepted. For aluminium, the cracking criteria given in 10.8.2 and 10.8.3 shall apply.

10.8.2 Aluminium slender anodes

The following cracking criteria apply:

- for sections of anode material not fully supported by the anode core, no visible cracks shall be permitted without magnification;
- cracks within the section of an anode supported by the anode core are not acceptable if the length is > 100 mm and/or the width > 1 mm;
- cracks penetrating to the steel anode cores or through the anode are not permitted;
- a maximum of 10 cracks per anode with small dense cracks counting as one and cracks $< 0,5$ mm wide not counted.

Longitudinal cracks are not permitted.

10.8.3 Aluminium bracelet anodes

The following cracking criteria apply:

- for sections of anode material not fully supported by the anode core, no visible cracks shall be permitted without magnification;
- cracks penetrating to the steel anode cores or through the anode are not permitted;
- cracks with a length of > 100 mm or > 50 % of the anode diameter (whichever is greater) and/or width > 3 mm are not acceptable.

Provided the above is satisfied, the following cracks are acceptable in transverse direction:

- cracks with a length of ≤ 50 mm or ≤ 20 % of the anode diameter, whichever is less, and a width < 3 mm;
- cracks with a length of 50 mm to 200 mm or between 20 % and 50 % of the anode diameter, whichever is less, and a width < 1 mm;
- cracks with a length of 50 mm to 200 mm are limited to two per half-bracelet or four per anode.

Cracks in the longitudinal direction shall be < 100 mm in length or < 20 % of anode length, whichever is less, and/or ≤ 1 mm in width.

10.9 Internal defects, destructive testing

The number and method of selection of anodes to be destructively tested (sectioned) within each anode type/size shall take into account anode design, the total number of anodes, and the pre-production test requirements (9.1).

If an anode does not meet the requirements below, an additional anode shall be subjected to destructive testing. If this does not satisfy the specified requirements, the whole anode lot should be rejected or other actions taken as agreed prior to fabrication.

Slender anodes should be sectioned transversely at 25 %, 33 % and 50 % of the nominal length, or at other agreed locations for a particular anode design. The cut faces, when examined visually without magnification, shall conform to the following criteria:

- Gas holes and porosities shall be limited to maximum 2 % of the total cut surface area, and maximum 5 % of any individual cut surface area. No cavity shall exceed 1 cm².
- Non-metallic inclusions shall be limited to maximum 1 % of the total cut surface area and maximum 2 % of any individual cut surface area. No non-metallic surface shall exceed 1 cm².
- Lack of bond (voids) shall be limited to maximum 10 % of the total tubular anode core circumference and maximum 20 % of the circumference for any individual cut.

Bracelet anodes should be sectioned transversely by cuts at 25 % and 50 % of the nominal length, or at other agreed locations for a particular anode design. The cut faces, when examined visually without magnification, shall conform to the following criteria:

- Gas holes and porosities shall be limited to maximum 2 % of the total cut surface area, and maximum 5 % of any individual cut surface area. No cavity shall exceed 1 cm².
- Non-metallic inclusions shall be limited to maximum 1 % of the total cut surface area and maximum 2 % of any individual cut surface area. No non-metallic surface shall exceed 1 cm².
- Lack of bond (voids) adjacent to the anode core shall be limited to maximum 10 % of the total anode core perimeter and maximum 20 % of any individual cut.

The conformance of the anode core position within the anode body in accordance with the design drawings shall be confirmed by physical measurement on the cut faces.

Other types of procedure qualification may be considered based on agreement between the end user and the relevant parties.

10.10 Electrochemical quality control testing

The following shall be assessed:

- closed-circuit potential;
- electrochemical capacity;
- corrosion pattern (uneven consumption, intergranular attack, passivity, etc.).

One set of tests shall be carried out for each 15 t of anodes produced. The electrochemical test data shall be reported.

Testing should be carried out in natural seawater or in artificial seawater in accordance with ASTM D1141.

The test should be conducted using the procedure described either in Annex E or in NACE TM0190^[12]. For testing in accordance with Annex E, test results shall meet the acceptance criteria in Table 8. For other testing procedures, acceptance criteria shall be documented in the test procedure.

Table 8 — Recommended acceptance criteria for electrochemical performance (production quality testing) using Annex E

Anode type	Minimum electrochemical capacity A·h/kg	Closed-circuit potential mV (Ag/AgCl seawater)
Aluminium	2 500	- 1 050
Zinc	780	- 1 030

If the specified requirements are not met, re-tests should be carried out on three specimens from each heat that failed to meet the requirements. Failure of any of these three specimens to meet the specified requirements should lead to rejection or other actions taken as agreed prior to fabrication of all anodes from the heat(s) involved.

The tested anode sample surface shall not show any signs of passivity or intergranular attack.

11 Galvanic anode installation

Welders and welding procedures should be qualified for any applicable welding process to a recognized standard such as AWS D1.1/D1.1M.

Bracelet anodes shall be bolted on, or welded to, the pipeline.

For bracelet anodes mounted on pipe joints that are concrete-weight-coated, electrical contact between the concrete reinforcement and the anodes shall be avoided by providing a gap, typically of 25 mm, at each end of the anode. Gaps between bracelet anode half-shells and between half-shells and the concrete shall be filled with non-conductive mastic or similar compound.

Anode installation shall be carried out in such a way that damage to the pipeline coating is minimized.

The connections of cables to the pipeline shall be designed to ensure adequate mechanical strength and electrical continuity and to prevent damage to the pipe at the point of connection. The removal of the protective coating from the pipe should be kept to a minimum. After installation of the cable-to-pipe connection, the coating shall be repaired using a compatible coating material.

A detailed cable-to-pipeline connection procedure shall be included in the CP design. Welding of cable connections shall not be carried out on bends or within 200 mm from pipeline welds.

For aluminothermic welding of cables, the welding procedure shall be such that copper penetration into the pipeline material shall be less than 1 mm and local pipeline hardness shall remain within the requirements given in the pipeline specification.

Aluminothermic weld charges should not be greater than 15 g. If cables larger than 16 mm² need to be attached, the cores shall be separated into a number of smaller strands, each measuring less than 16 mm² and welded separately.

Aluminothermic welding should not be carried out on corrosion-resistant alloy pipelines. Alternative methods such as pin brazing, soft soldering, adhesive bonding or friction welding may be used, provided that the detailed procedure and performance are reliable and properly documented.

All items to be protected by CP shall be electrically connected and should have a welded or brazed connection to an anode. All bolted or clamped components with a surface area exceeding 1 m² shall have an all-welded or brazed connection to an anode. For all bolted or clamped assemblies without an all-welded or brazed electrical connection, it shall be verified that the electric resistance is less than 0,1 Ω. The pipeline coating on contact surfaces shall be removed prior to making the connection.

Cables should be copper-cored, and shall be insulated and sheathed to withstand the prevailing chemical and mechanical conditions. The minimum conductor size for measurement cables shall be 4 mm². Cables shall be sized such that no excessive voltage drops occur which reduce the capacity of the system.

If the contact is made by using current-carrying copper cables welded or brazed at each end, these shall be stranded and have a minimum cross-section of 16 mm² and brazed to the cable shoe. At least two cables per anode shall be installed. For half-shell anodes, two half-shells shall be considered as a single anode.

When electrical continuity is to be achieved by direct welding of core extensions, a doubler pad should be pre-installed on the pipeline to avoid detrimental effects of the fillet welds and the external coating.

For pipelines coated with thick insulating coating systems, the anodes may be placed on the outside of the coating and electrical connection may be made to a steel bracket with a doubler pad arranged to provide a surface for the attachment which is flush with the outer diameter of the insulating coating.

After the attachment process, the area shall be coated with a compatible coating system.

Only in exceptional cases (e.g. the retrofit of a CP system or the use of remote anode assemblies) should the underwater installation of anodes, utilizing either bolted or clamped devices or welding, be carried out.

Bolted connections with set screws or friction welding may be considered for the electrical connection of anode retrofit systems.

12 Impressed-current CP systems

12.1 Current sources and control

NOTE Impressed-current systems utilize a transformer-rectifier as the current source. Statutory requirements can apply for its design, installation and operation.

Separate negative connections shall be installed for each pipeline to be protected, independent of any negative connection to the platform or any land-based installation. Negative connections shall be terminated in a control box. There shall be a facility to regulate and measure the protective current to each pipeline.

The control of the transformer-rectifier current output may be manual or automatic. In the first case, either current or voltage control may be used, while automatic control shall be based on potential readings from fixed reference electrodes. Alarm functions indicating excessive voltage/current load on anodes and/or too negative or too positive protection potentials should be included.

The current output from individual anodes should each be independently adjustable.

12.2 Impressed-current anode materials

Anode material should be mixed metal oxides or platinum on a substrate of titanium, niobium or tantalum, graphite, high-silicon cast iron, magnetite, precious metals or steel. Other impressed-current materials can be used in specific applications if they are reliable and properly documented. For land-based CP systems which are designed to protect offshore pipelines, alternative anode materials may be used if they are reliable and properly documented in accordance with ISO 15589-1.

NOTE The anode material and substrate determine the maximum operating voltage and anodic current density that can be utilized. Impressed-current materials suffer deterioration, the magnitude of which is dependent on the anodic current density and the applied voltage.

12.3 System design

WARNING — During operation of CP systems, chlorine gas can develop at anode surfaces and hydrogen gas can develop at cathode surfaces. To avoid any health and safety hazards, design and operation shall avoid any detrimental build-up of the gases.

Impressed-current anodes are located at the ends of submerged pipelines. The current output shall be sufficient to protect the pipeline to the mid-point. Impressed-current systems should be designed for larger current outputs than galvanic anodes and achieve a reduced current-distribution efficiency.

The high current output can result in overprotection of the pipeline nearest the impressed-current anodes. Current attenuation calculations should therefore be conducted to verify that mid-point protection can be achieved without overprotecting the ends (see Annex B)

The total electrochemical capacity of the impressed-current CP shall be at least 1,25 times the total demand of the pipeline calculated as described in Annex A.

To account for both uneven current distribution and a higher risk of anode malfunction compared to galvanic anode systems, the design of the impressed-current CP system shall include redundancy with respect to the number of anodes.

Impressed-current anodes and cables shall be designed to withstand all expected forces during installation and operation. Anodes shall be designed so that they can be replaced either from the surface or subsea by diver or ROV.

Where anodes are mounted within 1,5 m of the support structure, a non-conductive coating or sheet (minimum 1 mm thickness), i.e. a dielectric shield, shall be applied to the adjacent support surface.

NOTE 1 This precaution is to prevent excessively negative potentials. Typically, shields of prefabricated glass-fibre-reinforced sheets of epoxy resin are used, and may be an integral part of the anode assembly or fastened to the object with an epoxy resin. Alternatively, liquid-applied coatings such as glass-flake-reinforced epoxy or polyester can be applied.

Anode cables shall have a steel armour or shall be adequately protected by routing within a dedicated conduit. Provisions for repairs to and replacement of cables shall be incorporated in the design.

NOTE 2 Restrictions for routing of cables in hazardous areas can apply.

Platinum- or gold-coated titanium, niobium, and tantalum should be used for electrical contacts exposed to seawater.

Pipelines protected by impressed current shall be electrically isolated at both ends from adjacent structures/pipelines. Isolating joints should be located above water at a location suitable for inspection and maintenance. If interference effects from adjacent structures or pipelines are to be considered, connections for the installation of resistive bonds should be installed.

If impressed-current systems are used, fixed reference electrodes shall be installed to verify adequate CP of the pipeline and shall include potential monitoring in the area closest to the anode, i.e. to verify there is no overprotection. Critical areas where diver or ROV inspection is prevented shall have fixed reference electrodes.

Since fixed reference electrodes have a limited life, procedures for maintenance and on-line calibration should be established.

Positive and negative cables shall not be placed in a common conduit.

To evaluate the performance of the CP on offshore pipelines protected by an impressed-current system, measuring cables and test points shall be installed at each end of the pipeline if direct contact is not possible.

At isolating joints, two cables shall be connected to each side of the joint or flange. The cables shall be separately terminated in one test post or junction box with suitable facilities to install direct or resistive bonds. To enable reproducible monitoring, the test box should be installed in a convenient, safe location close to the riser, where there is vertical access to the seawater for riser-drop cell surveys.

12.4 Manufacturing and installation considerations

Manufacturing of impressed-current anodes, subsea electrical connectors and dielectric shields shall be performed according to an approved quality control system. Any welding or brazing of cables shall be carried out according to a recognized procedure.

12.5 Mechanical and electrical considerations

The electrical connection between the anode lead cable and the anode body shall be made watertight and mechanically sound.

Cable and connection insulating materials shall be resistant to chlorine, hydrocarbons and other deleterious chemicals.

Care shall be taken to provide suitable mechanical protection for both the anode and its connecting cable. On suspended systems, the individual anodes or anode strings should be equipped with winches

or other retrieval means as a damage-preventing measure during severe storms or for routine inspection and maintenance, and the implications of a loss of protection during these periods should be assessed.

NOTE 1 Impressed-current systems are more critical with respect to mechanical damage than galvanic anode CP systems because relatively few anodes are involved, each of which discharges a substantial amount of protective current. The loss of an anode or any negative return cable can seriously reduce system performance.

The following methods of installing fixed-type impressed-current anodes may be applied.

- Anodes can be bottom-installed on the ocean floor by mounting them on specially designed concrete sleds for stability. This minimizes the possibility of the anodes becoming covered with mud or silt.
- Anodes can be installed at the lower ends of protective vertical steel pipe casings or conduits attached to the platform. Casings should be attached to above-water platform members and supported at repeating members below water. The anodes should be lowered through the casings (which protect the anode lead wires) and be allowed to extend below a termination fitting at the bottom of each casing. This method provides a means of anode retrieval or replacement using the anode cable, without diver assistance. Marine growth or corrosion scale can make anode retrieval difficult or impossible. The top of the anode casing should be sealed with a removable cap to prevent any debris going down the casing.
- Anodes with essentially flat configuration-mounted, isolating-type holders can be attached directly to submerged platform members or to auxiliary structural members, such as vertical pipes, which can be removed for anode retrieval without diver assistance.
- Anodes can be installed on submerged platform members using offset steel structural support attached to the platform members. In this case, diver assistance is required for anode replacement.

Simple, rugged, easily maintained impressed-current equipment shall be used. The system can be based on manual, constant current or automatic potential control rectifiers.

NOTE 2 Because conditions at an offshore location seldom vary, except for weather-related factors, manually adjustable oil-cooled rectifiers with both a.c. and d.c. overload protection are commonly used.

There can be a delay of several months to a year or more between the time a pipeline is laid until permanent electrical power becomes available on the platform. Adequate CP of the pipeline for the interim period shall be provided.

Interference current corrosion on other pipelines and steel structures and reinforcement of concrete structures shall be assessed. Further guidance is given in Annex F.

13 Documentation

13.1 Design, manufacturing and installation documentation

The documentation for as-built systems shall cover the following:

- description of the basis of the CP design with reference to project specifications, codes and standards;
- calculations of surface areas to be protected and currents demanded;
- final design anode calculations including anode mass, dimensions, resistance, numbers and performance;
- drawings, including anode distribution, detailed anode design, manufacturing and installation.

The final documentation shall contain the engineering drawings and equipment lists updated to “as-built” status, and certification covering anode manufacturing and testing.

The following additional documentation shall be included for impressed-current systems:

- transformer-rectifier documentation, including capacity, control and alarm facilities and circuit drawings;
- detailed drawings of anodes, reference electrodes, subsea connectors, cable terminations and dielectric shields;
- procedures for fastening anodes, reference electrodes and dielectric shields, if applicable;
- documentation of impressed-current anode performance;
- drawings showing location of anodes and reference electrodes;
- detailed drawings of cables and electrical isolating joints, if applicable;
- drawings of cable protection conduits;
- documentation of potential-monitoring system.

A schedule of materials to be used for the installation of the CP system shall be issued, listing the specified materials in the quantities required to construct the CP system.

Construction details and installation procedures for the CP system shall be provided.

13.2 Commissioning procedures

For galvanic anode systems, commissioning is generally not necessary.

For impressed-current systems the commissioning procedures shall include:

- testing of pipeline isolation where present;
- energizing CP hardware, if necessary;
- measurement of adequate protection levels (see Annex D);
- interference testing, if applicable.

13.3 Operating and maintenance manual

For impressed-current systems, an operating and maintenance manual shall be provided containing:

- a description of the system and system components;
- a commissioning report;
- drawings for as-built components/systems;
- manufacturer/supplier documentation;
- potential criteria for the system;
- a monitoring plan, including procedures, schedules and equipment for each type of monitoring facility installed on the pipeline;
- guidelines for the safe operation of the CP system;
- maintenance procedures.

14 Operation, monitoring and maintenance of CP systems

14.1 General

Details of inspection and monitoring shall be performed in accordance with Annex D. Details of interference are given in Annex F.

14.2 Monitoring plans

A monitoring plan shall be written as part of the design.

The monitoring plan should consider the following:

- required types of measurement, such as pipe-to-seawater potentials, anode potentials, anode current outputs, visual inspection of anode dimensions, pipeline isolation testing, etc.;
- locations at which measurements are to be carried out;
- any permanent monitoring facilities;
- required monitoring installations and equipment to carry out such surveys;
- description of the techniques to be used, such as monitoring by divers, ROVs, trailing wires, towed fish, etc.; this description shall also include methods for accurately locating the pipeline, and the construction-phase requirements concerning the acquisition of navigation data for this purpose;
- frequency of each type of measurement.

This plan shall be part of the operating and maintenance manual.

14.3 Repair

Remedial measures shall be implemented if periodic surveys and inspections reveal that protection no longer meets the design criteria. In such cases the installation of additional anodes can be required.

Anode cables can be attached to the pipeline by mechanical fixing devices or by welding to an approved procedure (e.g. friction welding). Electrical resistance of such connections should be less than 0,1 Ω .

NOTE Mechanical fixing devices might not give reliable electrical connections for long-term applications.

Future inspections should include checks on all retrofitted galvanic anodes which rely upon mechanical contact with the pipeline for electrical continuity (e.g. the measurement of potential on both the anode and the pipeline immediately adjacent to the attachment point).

Annex A (normative)

Galvanic anode CP design procedures

A.1 Introduction

Annex A specifies the detailed design procedures of CP systems based on galvanic anodes.

A.2 Subdivision of pipeline

Pipelines may be divided into sections where changes in conditions, such as water depth, operating temperature or burial, can give rise to variations in design current density.

A.3 Surface area calculations

For each pipeline section, the surface areas to receive CP shall be calculated separately where conditions cause different current requirements.

Components to be connected electrically to the pipeline, such as risers, expansion loops, tie-in spools, valves and tees, shall be included in the surface area calculations.

A.4 Current demand calculations

From the pipeline dimensions and the coating selected, the mean current demand, I_{cm} , and the final demand (I_{cf}) shall be calculated separately from Equation (A.1).

$$I_c = A_c \times f_c \times i_c \quad (\text{A.1})$$

where

I_c is the current demand for a specific pipeline section calculated for mean and final conditions, in amperes;

i_c is the current density, selected for mean and final conditions (see 7.4), in amperes per square metre;

f_c is the coating breakdown factor determined for mean and final conditions (see 7.5);

A_c is the total surface area for a specific pipeline section, in square metres.

A.5 Selection of anode type and dimensions

The type of anode shall be determined from fabrication, installation and operational considerations.

The internal diameter of bracelet anodes shall be determined from the nominal outside diameter of the pipe plus maximum specified coating thickness, maximum pipe diameter tolerances and pipe ovality.

For pipeline bracelet anodes mounted flush with the concrete coating, the thickness of the concrete coating layer shall be taken into account when determining the overall dimensions of the anode.

The anode dimensions shall be sufficient to meet the required current demand at the end of the design life.

A.6 Total anode mass calculations

The total net anode mass required to maintain CP throughout the design life shall be calculated for each section of pipeline in accordance with Equation (A.2).

$$m = I_{cm} \times t_{dl} \times \frac{8760}{\mu \times \varepsilon} \quad (\text{A.2})$$

where

- m is the total net anode mass, for the specific pipeline section, in kilograms;
- I_{cm} is the mean current demand for the specific pipeline section, in amperes;
- t_{dl} is the design life, in years (7.3);
- ε is the electrochemical capacity of the anode material per kilogram (8.3), in ampere hours;
- μ is the utilization factor (8.4).

A.7 Calculation of anodes, dimensions and net mass

The final dimensions and net mass of the individual anodes shall be optimized, by carrying out a number of re-iterative calculations, using the equations below.

The total net anode mass is given by Equation (A.3).

$$m = n \times m_a \quad (\text{A.3})$$

where

- n is the number of anodes to be installed on the specific pipeline section;
- m is the total net anode mass, in kilograms, for the specific pipeline section [from Equation (A.2)];
- m_a is the individual net anode mass, in kilograms.

The minimum number of anodes n shall be determined considering the maximum allowable anode spacing (8.1). For bracelet anodes, anode spacing is set at a fixed number of field joints. For sled anodes, the anode spacing is usually set at an easily defined spacing (e.g. the calculated spacing may be 1 187 m but a spacing of 1 000 m is selected).

NOTE 1 The anode manufacturers usually have standard-size moulds available for specific line sizes. Although Equation (A.3) is correct, in practice n and m_a are selected using Equation (A.4).

$$m > n \times m_a \quad (\text{A.4})$$

The required end-of-life individual anode current output, I_f , shall be calculated from Equation (A.5).

$$I_f = \frac{I_{cf}}{n} \quad (\text{A.5})$$

where

- I_f is the required end-of-life individual anode current output, in amperes;
- I_{cf} is the total current demand for the protection of the specific pipeline section at the end of life, in amperes;
- n is the number of anodes to be installed on the specific pipeline section.

For a given anode size and mass, the actual individual anode current output at the end of life, I_{af} , is calculated from Equation (A.6).

$$I_{af} = \frac{E_c - E_a}{R_a} \quad (\text{A.6})$$

where

I_{af} is the actual end-of-life individual current output, in amperes;

E_a is the design closed-circuit potential of the anode, in volts (see Table 5);

E_c is the design protection potential, in volts, i.e. minimum negative potential (see Table 1);

R_a is the total circuit resistance, which is assumed to be equivalent to the anode resistance, in ohms (see A.8).

For determining the end-of-design-life anode-to-seawater resistance, the anodes shall be assumed to be consumed to an extent given by their utilization factor. The approximate anode dimensions corresponding to this degree of wastage shall be used in the anode resistance formula for R_a (see A.8).

NOTE 2 $E_c - E_a$ is generally referred to as the design driving voltage, in volts.

To provide the required current, the actual anode current output shall be greater than or equal to the required current output:

$$I_{af} \geq I_f \quad (\text{A.7})$$

Equations (A.4) to (A.7) should be used to optimize the number, size and individual mass of the anodes to be used. For anodes that meet the criteria of Equations (A.4) and (A.7), an economic optimization may be carried out considering anode fabrication and installation cost.

A.8 Anode resistance equations

The anode resistance shall be calculated as follows:

a) for bracelet anodes

$$R_a = 0,315 \times \frac{\rho}{\sqrt{A}} \quad (\text{A.8})$$

b) for slender anodes:

$$R_a = \frac{\rho}{2 \times \pi \times L} \times \left(\ln \frac{4L}{r} - 1 \right) \quad (\text{A.9})$$

where

R_a is the anode resistance, which is assumed to be equivalent to the total circuit resistance, in ohms;

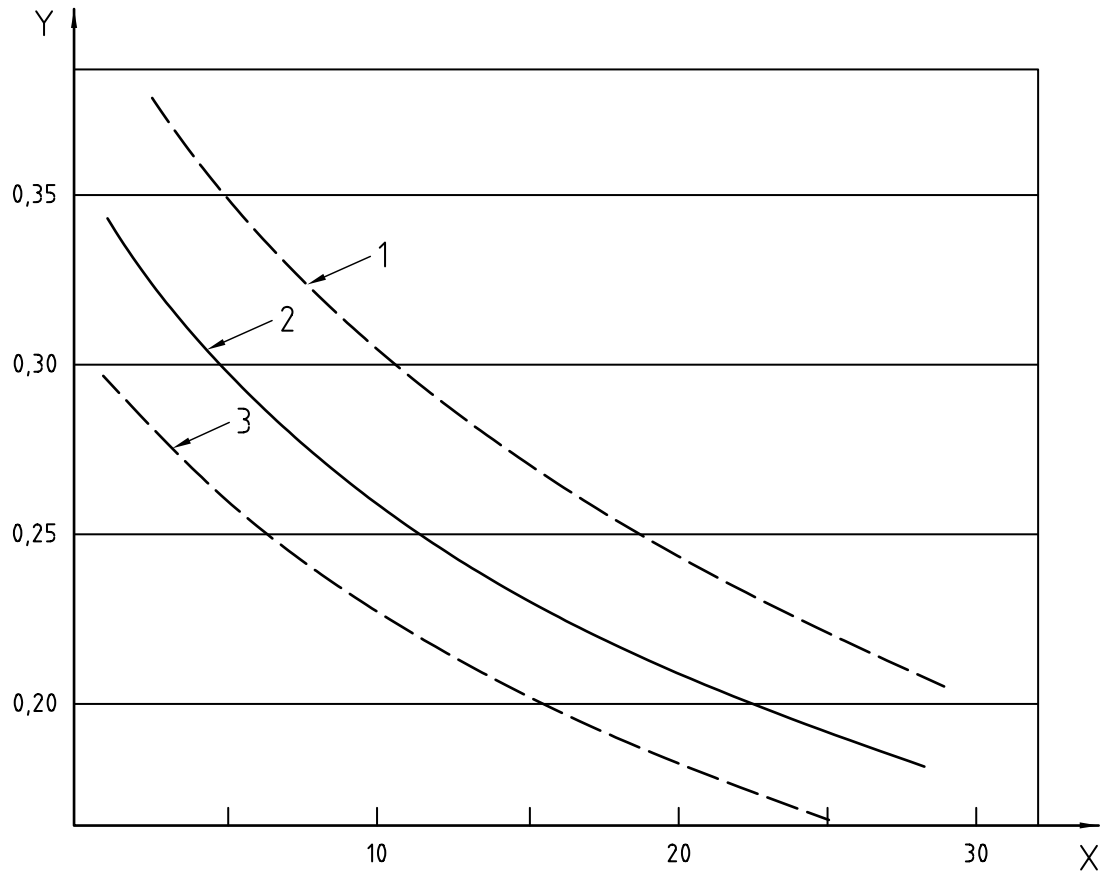
ρ is the environmental resistivity, in ohm metres;

L is the length of the anode, in metres;

r is the radius of the anode, in metres;

A is the exposed surface area of the anode, in square metres.

Typical seawater resistivities are shown in Figure A.1.



Key

- X temperature, °C
- Y seawater resistivity, ρ , $\Omega \cdot m$
- 1 salinity 3,0 %
- 2 salinity 3,5 %
- 3 salinity 4,0 %

Figure A.1 — Seawater resistivity as a function of temperature for salinities 3,0 % to 4,0 %

For anodes exposed to seabed environments, the resistivity should be assessed by measurements or previous experience. If no data are available, 1,5 $\Omega \cdot m$ should be used.

For non-cylindrical anodes, the radius, r , in Equation (A.9) shall be calculated from Equation (A.10).

$$r = \frac{C}{2\pi} \tag{A.10}$$

where

- r is the radius of the anode, in metres;
- C is the cross-sectional perimeter, in metres.

Other anode resistance equations may be validated by theory and/or testing.

A.9 Design adjustments for varying conditions

The coating breakdown factor, f_c , and the electrochemical capacity, ϵ , used in the typical CP design assume that the operating conditions for the pipeline will not vary over the life of the pipeline. If this

assumption is not correct, the values used in Equations (A.1), (A.2) and (A.6) will not be constants, but will vary as the operating conditions change. The impact of these varying conditions upon the CP design may be evaluated by repeating the design calculations at the extremes of the expected conditions. If the difference between the two anode designs is small, the most conservative design should be used. However, if the number of anodes required by the two designs is significantly different, a design that addresses these changes may be developed.

EXAMPLE 1 For high-temperature pipelines installed several years before the start of production, cathodic current requirement during the period prior to start-up will be less due to the cooler temperature.

EXAMPLE 2 For buried flowlines that can experience increasing operating temperatures as water production increases later in its operating life, cathodic current requirements will be much less during the initial period of production than in the later high-temperature period. Since the anode operating temperature can change with time, the electrochemical capacity can vary as the temperature increases.

EXAMPLE 3 Pipelines with exceptional coating quality and a high cathodic current density requirement, such as deepwater insulated lines, may require such small amounts of current that the anode current density of a conventional anode bracelet design is below 1 000 mA/m². The electrochemical capacity of aluminium alloys is not a constant value at anode current densities below 1 000 mA/m².

Anode electrochemical capacity is usually tabulated as high and low temperature values at anodic current densities in excess of 1 000 mA/m². For normal operating temperatures less than 50 °C and anode current densities over 1 000 mA/m², this variation may be ignored.

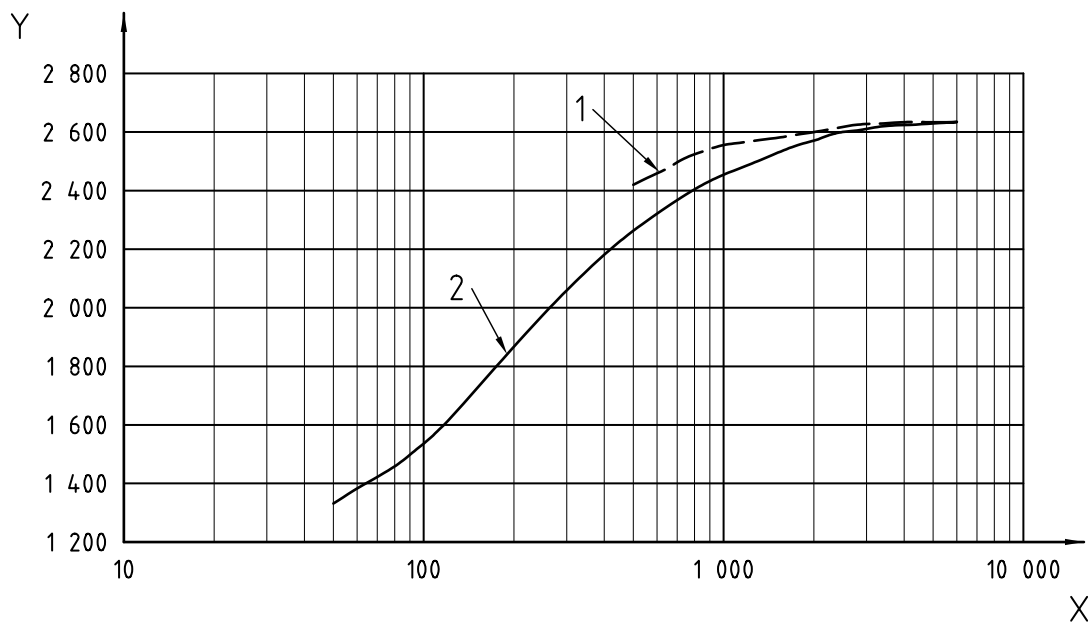
NOTE Examples 2 and 3 listed above describe applications that fall either outside the normal anode operating envelope or where the operating conditions will change over the life of the anode (as an example, see Figure A.2 which gives curves of anode electrochemical capacity versus anode current density for two specific temperature ranges). In these situations, the anode electrochemical capacity, ϵ , changes over the life of the pipeline.

To account for these changing conditions, a single value for the anode electrochemical capacity may not be appropriate in Equation (A.2). If variable electrochemical capacities are envisaged, then Equation (A.2) should be revised by Equation (A.11).

$$m = \frac{A_c \times 8760}{u} \int_t i_c \times f_c \times \frac{1}{\epsilon} dt \quad (\text{A.11})$$

where i_c , f_c and ϵ are not constant values but vary over the design life of the pipeline.

Information about ϵ as a function of temperature and/or current density may be obtained in accordance with Annex C. Normally, these calculations are performed as numerical integrations using a spreadsheet that allows the annual value for m to be calculated and then summed over the life of the pipeline.



Key

- X anode current density, mA/m²
- Y anode electrochemical capacity, A·h/kg
- 1 T = 2 °C
- 2 T = 25 °C to 28 °C

Figure A.2 — Aluminium anode performance in seawater at low current densities

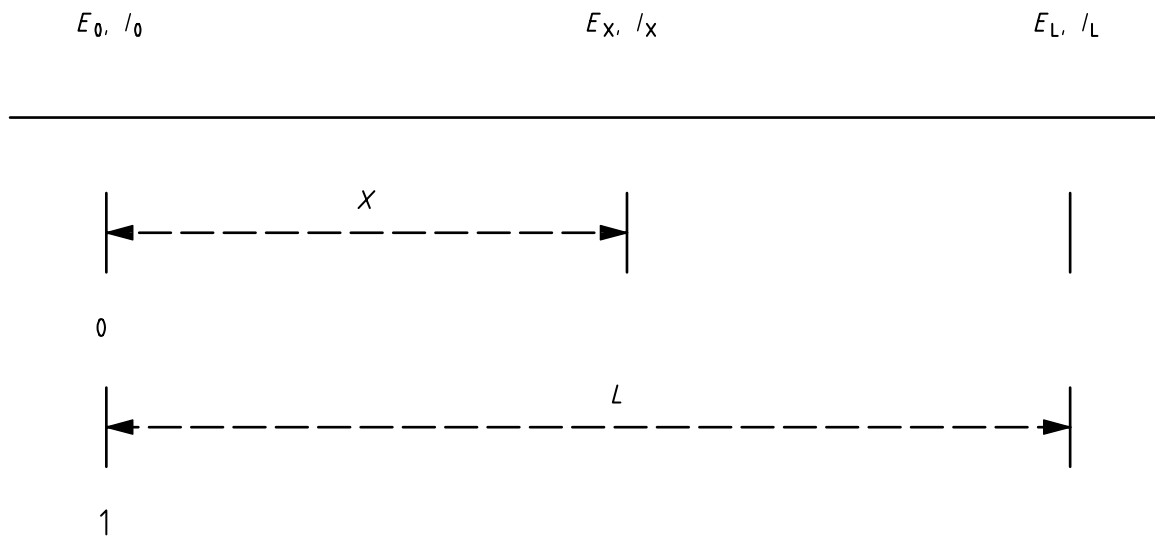
Annex B (normative)

Attenuation of protection

B.1 Introduction

Once the number, size and spacing of the anodes have been determined in accordance with Annex A, an approximate check on the suitability of the anode distribution can be carried out using attenuation equations. Using these equations, it is possible to obtain an indication of the distribution of the pipe-to-electrolyte potential and the current flowing onto the pipeline a function of the distance from the drain points (i.e. anodes).

Figure B.1 provides an illustration of the potential and currents as a function of the distance from the drain point.



Key

1 drain point

NOTE The symbols used in this figure are defined in B.2.

Figure B.1 — Drain point definition

B.2 Method

For a pipeline with multiple drain points (anodes) at a uniform spacing of $2L$, the potential, E_x , and current, I_x , at any distance x from the anode shall be calculated using Equations (B.1) and (B.2):

$$E_x = E_0 \times \frac{\cosh \alpha (L - x)}{\cosh \alpha L} \quad (\text{B.1})$$

$$I_x = I_0 \times \frac{\sinh \alpha (L - x)}{\sinh \alpha L} \quad (\text{B.2})$$

where

E_0 is the pipe-to-electrolyte potential shift at the drain point (anode), in volts;

E_x is the pipe-to-electrolyte potential shift at a distance x from the drain point, in volts;

I_0 is the current flowing onto the pipe at the drain point (anode), in amperes;

I_x is the current flowing onto the pipe at a distance x from the drain point, in amperes;

L is half the distance between drain points, in metres;

R_L is the linear electrical resistance of the section of the pipeline, in ohms per metre, and is given by: $R_L = \frac{\rho}{A_w}$;

R_t is the leakage or transverse resistance, in ohm metres, and is equal to $\frac{R_0}{\pi D_o}$;

R_0 is the pipe-to-electrolyte insulation resistance, in ohm square metres;

ρ is the specific resistance of the pipeline material, in ohm metres;

D_o is the external diameter of the pipeline, in metres;

A_w is the cross-sectional area of the pipe wall, in square metres;

α is the attenuation constant for the pipeline section, in reciprocal metres, and is equal to $\sqrt{\frac{R_L}{R_t}}$.

A value for the insulation resistance R_0 should be selected based upon practical experience and consider the following:

- type of coating;
- exposure conditions such as to seawater or seabed sediments;
- design life of the pipeline and anticipated progressive reduction in coating resistance over the design life;
- pipeline installation method and projected extent of coating damage.

The linear electrical resistance of the section of the pipeline R_L may be calculated from Equation (B.3):

$$R_L = 4L \cdot \frac{\rho}{\pi(D_o^2 - D_i^2)} \quad (\text{B.3})$$

where

D_o is the outer diameter of the pipeline;

D_i is the inner diameter of the pipeline;

L is half the distance between the drain points, in metres.

Alternatively, values for the electrical resistance for standard pipe sizes may be obtained from tables in Reference [11].

B.3 NORSOK procedure

The procedure given in this clause may be used for determining the maximum distance between anodes.

NOTE Reference [13] provides further information for this method. Using this method, the maximum voltage drop is calculated by assuming that the whole area with coating breakdown is located halfway between the anodes.

The voltage drop (or potential increase) between two anodes for a CP design based on anodes equally distributed along the pipeline should be calculated using Equation (B.4).

$$\Delta E_{Me} + \Delta E_A = \frac{L^2 \times \rho_{Me} \times i \times f_{cf} \times D}{4 \times d \times (D - d)} + R_{anode} \times i \times \pi \times D \times f_{cf} \times L \quad (B.4)$$

where

ΔE_A is the IR drop due to transporting the current from anode to cathode, electrolytic potential drop (V);

ΔE_{Me} is the IR drop due to transporting the current in the pipe wall, metallic potential drop (V);

R_{anode} is the anode resistance which is assumed to be equivalent to the electrolytic resistance, in ohms;

ρ_{Me} is the resistivity of the pipe wall material, in ohm metres;

L is the length between anodes, in metres;

i is the current density, in A/m²;

f_{cf} is the final coating breakdown factor (see 7.5);

D is the pipeline outer diameter, in metres;

d is the pipeline wall thickness, in metres.

For anodes distributed along a pipeline, loss of one anode shall be taken into account when calculating the maximum distance between the anodes; see also 8.1.

For a CP design with anode banks located at the pipeline ends only, the voltage drop (or potential increase) between the two anode banks should be calculated using Equation (B.5).

$$\Delta E_{Me} + \Delta E_A = \frac{L^2 \times \rho_{Me} \times i \times f_{cf} \times D}{4 \times d \times (D - d)} + \frac{R_{anode} \times i \times \pi \times D \times f_{cf} \times L}{2} \quad (B.5)$$

Equation (B.5) is valid only if the pipeline section and the anode pipe joints are unaffected by other installations at the pipeline ends. If this condition is not fulfilled and such structures can draw current from the anodes, then the last part of Equation (B.5), which represents the voltage drop from the anode, shall be further developed to account for such effects. A special assessment of the anode voltage drop shall also be made when the pipeline is protected from anodes on a structure at the pipeline end. In cases where end mounted anodes are used in combination with anodes or anode spools along the pipeline, a combination of Equation (B.4) and Equation (B.5) shall be used.

Annex C **(normative)**

Performance testing of galvanic anode materials

C.1 General

This annex provides a procedure for laboratory testing for determining performance values for galvanic anodes in a given environment.

The performance of galvanic anode materials may also be validated by field experience, either by using data from monitored anodes or by dedicated field-testing of full-size anodes.

This procedure is also applicable to special environments, such as hot seawater or sediments.

Performance testing shall be carried out for new (nominal) anode compositions and/or foundry, and whenever there is a need to verify anode material performance.

C.2 Sampling and preparation of test specimens

Material for testing shall be sampled either from manufactured anodes or from special castings using the same raw materials and melting practice as for normal production.

Two specimens shall be prepared from materials representing a minimum of five heats. The chemical composition of the material test samples shall be representative of normal production, i.e. the content of alloying and impurity elements shall reflect the manufacturers' internal composition limits for the anode material.

Cylindrical specimens with a minimum diameter of 20 mm and a minimum length of 80 mm shall be machined from the sample material.

A hole with a diameter of approximately 2 mm shall be drilled through the test specimen, tapped at one end and connected to a titanium support rod. The support rod shall have an electrically insulating coating on all areas which will be exposed to the test solution.

After mounting on the support rod, the specimen ends shall be coated by a sealing compound such as polychloroprene glue or silicone rubber.

Prior to exposure, the test specimens shall be rinsed in tap water and then dried with ethanol or equivalent. After drying, the specimens shall be weighed to the nearest 0,1 mg.

C.3 Testing equipment and experimental procedure

The testing environment shall be clean natural seawater with a salinity $\geq 3,0$ % mass fraction. The temperature of the testing environment may vary in the range +7 °C to +20 °C. Temperature and salinity of the test environment shall be recorded at least once per week.

The test cells shall be configured as outlined in Annex E with a continuous exchange of seawater in the cell at a rate of at least 1 l/min. The seawater shall be continuously purged with air.

Testing shall be performed as a free-running test.

The duration of the test shall be a minimum of 12 months.

The integrated current may be determined by a coulometer or by recording the voltage drop across the precision resistance to be introduced in the circuit. Manual readings of the integrated current shall be taken at least once a week.

Manual recordings of anode potentials (see Annex E) shall be taken at least once a day for 5 days during the first 2 weeks of testing, and at least once a week thereafter. Continuous recording may be used as an alternative.

The anode and cathode areas shall be connected across a 10 Ω precision resistor in order to limit the anode current density. Higher and lower circuit resistances (e.g. 2 Ω to 20 Ω) may be applied if more extensive data are required. The cathode surface area shall be at least 30 times the exposed anode surface area.

The anode current density shall be calculated from the voltage drop across the 10 Ω circuit resistance using a high-impedance ($>10^7 \Omega$) voltmeter.

Measurements of current and anode potential shall be made at regular intervals. Steel cathode potentials shall also be recorded at the same time.

The electrochemical capacity shall be calculated as specified in Annex E.

C.4 Documentation

A test report containing the following shall be prepared:

- a) data from melting and casting of the test material, including alloying and impurity elements affecting anode performance;
- b) nominal composition and guaranteed compositional limits;
- c) specimen preparation, testing equipment and procedures;
- d) environmental data, including seawater temperature and salinity;
- e) anode potentials presented graphically as a function of time;
- f) photographs of anode specimens prior to and after cleaning;
- g) electrochemical capacity, in ampere hours per kilogram.

Annex D (normative)

CP monitoring and surveys

D.1 Introduction

A number of methods may be employed to monitor the effectiveness of offshore pipeline CP. The level of monitoring shall be commensurate with the criticality and condition of the pipeline, and minimum requirements of regulations.

A post-installation survey should be carried out within 12 months of pipeline installation in accordance with D.6.1.

Further surveys should be considered based on:

- CP design and anode performance in accordance with this part of ISO 15589;
- results from the initial survey;
- reported excessive anode consumption;
- presence of coating damage which may result in breakdown factors larger than those given in Tables 3 and 4; and
- potential interference with neighbouring pipelines and structures.

If the pipeline is to remain in service beyond its original design life, then at least one potential survey shall be performed within the last 5 years of the design life of the CP system (see D.6.2).

D.2 Topside potential monitoring

Measurements of potentials applied to pipeline risers may be carried out by using a simple portable reference electrode and a conventional voltmeter. The voltmeter negative terminal shall be connected to the riser above the water line, and the positive terminal to the reference electrode. The reference electrode shall be lowered into the water alongside and, to ensure accuracy, as close as possible to the riser. Potentials shall be recorded at different depths determined from markers attached to the reference electrode cable.

NOTE 1 Motion of the water and loss of visual contact with the reference electrode reduces measurement accuracy. However, accuracy can be restored if a diver is employed to ensure good positioning of the reference electrode. When divers or ROVs are used for measuring potential, specially designed contact probes are used (see D.4.3.1). Electrical contact between the riser and host structure shall be checked, if considered possible, prior to reading potentials.

NOTE 2 The potential of risers can be influenced by the host structure if in electrical contact with the host structure. However, the potential of the riser is not necessarily a good indicator of the potential profile along the whole pipeline.

The potential on short pipelines running between two platforms may be modelled using attenuation equations, and the worst-case potential value predicted from the potentials measured at the extremities. Potential measurements shall be carried out at intervals along the pipeline for verification of model reliability.

NOTE 3 The length of such pipelines is dependent upon pipe wall thickness and diameter, external coating condition, operating temperature, degree of burial, end-point potentials, impressed-current anode location, galvanic anode condition and spacing, and whether or not the pipeline is effectively isolated from the host structure(s).

D.3 Visual inspection

Visual inspection of unburied sections should be carried out when necessary to check the condition of the pipe, coating and CP system. The type of data to be gathered during the inspection shall be documented prior to the inspection and be appropriate for the needs of the pipeline.

NOTE Direct visual inspection by divers or ROV cameras can disclose deficiencies of a CP system, such as damaged or missing anodes, damaged cables, excessive anode consumption. Apparent corrosion damage or rust discoloration can be another sign of under-protection. Low anode consumption can indicate passivation, and heavy calcareous deposits close to the anodes can indicate overprotection.

Galvanic anode surfaces should be cleaned before any physical measurements of anode dimensions are taken.

D.4 Potential measurements

D.4.1 General

Potential measurements should be taken to assess the performance of the CP system in accordance with this part of ISO 15589.

The objective of potential measurements is to determine the actual potential at the pipe-to-seawater interface with respect to a reference electrode, such that the effectiveness of CP can be assessed. Acceptance criteria are given in Table 1 and may be converted for different reference electrodes as detailed in D.4.2. Normally it is difficult to measure pipe-to-seawater potentials directly, as bare steel is not usually available. In such cases, indirect potential measurements should be considered.

Potential measurements should also be taken at galvanic anodes to obtain information on their performance.

When CP is achieved using impressed-current systems, the potential shall be measured with the protective current applied.

NOTE 1 The value includes the voltage drop across the steel/water interface, and also includes the voltage drop in the seawater between the reference electrode and the pipe.

In most circumstances, except near impressed-current anodes, the voltage drop in the seawater may be taken as zero.

Test equipment shall be maintained and periodically calibrated. Reference electrodes shall be checked for contamination and routinely calibrated against a standard laboratory-grade reference electrode.

Reference electrodes shall be positioned as close to the pipeline as practical, in particular for measurements of anode potentials with large voltage drops in the seawater adjacent to the anode. In these cases, the IR drop shall be compensated for when interpreting the measured anode potential in terms of the true anode potential.

Anode potentials should be more negative than the design closed-circuit anode potential.

NOTE 2 More positive recordings indicate excessive current load or passivation behaviour.

Electrical safety shall be observed when divers work on pipelines protected by an impressed-current CP system.

The steel/sea water potential shall be measured to determine whether a structure is adequately protected. For such measurements, connections shall be made to both the structure and the electrolyte.

NOTE 3 The connection to the structure is a simple metallic one but, for the connection to the electrolyte, a metal conductor has to be introduced into the electrolyte. This conductor introduces its own electrode potential, which inevitably becomes included in the measured value. This situation can be resolved by using a conductor of reproducible and defined electrode potential; this is called a reference electrode. Irrespective of the type of reference electrode used, it is essential that it be placed very close to the metal surface as the measurement of the potential difference between the metal surface and the electrolyte can be considerably affected by the potential drop produced by the protection current as it flows through the surrounding electrolyte to the structure. This effect, known as the IR drop, has the effect of making the measured potential more negative than the actual potential at the metal/electrolyte interface. The IR drop is dependent on electrolyte resistivity and is particularly relevant to buried structures. The resistance of any coatings will also have an effect.

D.4.2 Reference electrodes

Reference electrodes such as the saturated calomel electrode or various silver/silver chloride electrodes with different concentrations of KCl electrolyte may be used as master reference electrodes. Two electrodes in the same assembly, to give an on-line cross-calibration, should be considered for potential-monitoring devices.

NOTE 1 Saturated calomel electrodes or silver/silver chloride/potassium chloride electrodes are not often used for monitoring and controlling cathodic protection systems in seawater because they are insufficiently robust for field use. Reference electrodes used more often in the field are silver/silver chloride/seawater electrodes or high-purity or anode-alloy-specification zinc electrodes. These electrodes are considered sufficiently accurate for most practical purposes even if the electrolyte is not fully defined and reproducible. The silver/silver chloride/seawater (Ag/AgCl/seawater) electrode is the most widely used electrode for seawater applications, particularly in conjunction with portable monitoring equipment.

Other reference electrodes that may be used in place of the Ag/AgCl/seawater reference electrode are described below, with the respective protection potentials for carbon steel equivalent to the $-0,80$ V versus Ag/AgCl/seawater criterion.

- a) Saturated copper/copper sulfate reference electrode (CSE). The least negative potential measured against this electrode shall be $-0,85$ V. This electrode is more commonly employed for determining the level of protection on onshore pipelines and is not sufficiently stable in seawater for long-term immersion in this environment. It is not recommended for use in seawater.
- b) High-purity metallic zinc electrode. "High purity" (ASTM B418, type II, or EN 12496, alloy type Z2) or a zinc alloy used for anode manufacturing (US Mil Spec A-18001K or EN 12496, alloy type Z1 or Z3) have a moderately stable potential in seawater and are sometimes used as a reference electrode. However, zinc electrodes are less accurate than silver/silver chloride reference electrodes, and are mostly used in permanent monitoring applications. For permanent installations, a small anodic current should pass through the surface to keep it clean and active. The least negative potential for effective CP of carbon steel versus the zinc/seawater electrode is $+0,25$ V.
- c) Saturated calomel reference electrode (SCE). This electrode comprises mercury and mercurous chloride in a saturated solution of potassium chloride. The least negative potential for effective CP of low-alloy steel is $-0,78$ V. This electrode is not normally used for site surveys and is more suitable for laboratory applications.
- d) Saturated silver/silver chloride (Ag/AgCl/saturated KCl). This electrode is similar to the silver/silver chloride/seawater electrode, except that the silver/silver chloride is immersed in a saturated solution of potassium chloride and the potential is not affected by the salinity (or resistivity) of the seawater. The least negative potential for effective CP of low-alloy steel using this electrode is $-0,76$ V. As with SCE, the saturated silver/silver chloride electrode is more suitable in laboratory applications.

Reference electrodes used in the field shall be periodically checked with a master reference electrode having a valid calibration certificate. The master electrode shall be calibrated periodically with a

minimum frequency of once a year to a primary calibration reference electrode (normal hydrogen electrode; NHE).

Reference electrodes such as the saturated calomel electrode or various silver/silver chloride electrodes with different concentrations of KCl electrolyte may be used as master reference electrodes.

NOTE 2 The official reference electrode is the standard hydrogen electrode (SHE). This electrode considers the fugacity coefficient for hydrogen gas and the activity coefficient for H^+ ions but is practically impossible to manufacture.

D.4.3 Direct contact instruments

D.4.3.1 Contact probes

Potential measurements may be made above water using a conventional voltmeter connected to the reference electrode via a cable, and a second cable from the metal tip of the contact probe to the negative terminal on the voltmeter. The second cable should not be connected to the above-water section of a pipeline riser.

NOTE Contact probes comprise a reference electrode in a robust housing with a metal tip to make direct contact with the pipeline. They are designed for diver- or ROV-assisted potential surveys. They can be used in proximity mode, similar to topside monitoring (see D.2), but have the added ability to contact the structure locally via the metal tip. This is important if a pipeline is isolated and topside ground connection to the voltmeter is not possible.

Potential measurements may also be made by self-contained contact probes which are similar to the tip-contact probe, but in addition to the reference electrode have an integral voltmeter and do not require any cables back to the surface. These probes can be diver-held or ROV-mounted, and only work in the tip-contact grounding mode. Readings are displayed subsea and are either recorded visually, on video tape, or relayed verbally to a surface data recorder by the diver.

D.4.3.2 Fixed/permanent systems

Critical pipelines, such as those operating at high temperatures, inaccessible risers or pipelines in environmentally sensitive areas, can be equipped with permanent CP monitoring facilities. For these pipelines, a number of devices can be used, such as permanent reference electrodes, steel coupons for contact to pipeline, current density coupons (either bare steel or coated), and anode current monitoring shunts.

Monitoring devices should be connected to a topside facility such as a data logger via a cable or interrogated via an acoustic link. Battery life, cost and practicality should be considered for acoustically linked devices.

NOTE 1 Acoustically linked devices require battery packs, and interrogating them is a labour-intensive task.

NOTE 2 Distribution of monitoring devices over the entire length of the pipeline is impractical. Permanent monitoring facilities are more appropriate for risers or on sections of the pipeline within a fairly short distance from the platform or the shoreline.

D.5 Anode current measurements

Current density and electric field gradient measurements may be used to verify that galvanic anodes in unburied pipelines are active. For buried pipelines, locating anodes can be more restricted, and tracking capabilities, depth of burial and anode current output should be considered. Calculation of anode current output can be performed if highly accurate measurements of the magnitude and direction of the electric field or current are available.

NOTE There are several techniques for on-line measurements of galvanic anode current output. Such data are applicable to calculations of remaining anode life and can be used to optimize future designs.

D.6 Surveys

D.6.1 General

An underwater visual survey for main trunklines and other critical pipelines shall be conducted during or after the installation to determine if any damage to the CP system has occurred. The survey may include a determination of the pipeline potential along its length, current output from galvanic anodes from field gradient measurements, and coating condition assessments. If a baseline survey for a galvanic anode CP system confirms that the corrosion-control system is working as designed, it may not be necessary to carry out the next CP survey on the pipeline for many years.

Results from previous inspections should be used for planning future inspections. Attention shall be concentrated to areas where marginal or insufficient CP has been identified during previous surveys and in areas where damage to anodes and/or coating has been reported.

Localized or full-length surveys shall be carried out more frequently where inadequacies in the level of protection are known or suspected, due to

- known shortcomings in the original CP design,
- damage to the pipeline or the CP system,
- damage from third-party interference,
- pipeline approaching the end of the CP system design life if intended to operate beyond.

Where complete periodic surveys are impossible because of inaccessibility, surveys may alternatively be carried out on a sampling basis.

Buried pipelines are in general difficult to survey, as visual examination for coating condition and damage to CP facilities, in particular anodes, is not possible. Account should be taken of this in risk assessments.

D.6.2 Methods

Different survey methods, including potential measurement by direct contact with the pipeline or field gradient measurements using two or more reference electrodes at fixed distances from each other and from the pipeline, are available.

The most complete and accurate systems of potential measurement employ a diver or ROV to physically swim along the pipeline and take point readings at intervals, using a CP probe with a tip contact and an in-built reference electrode. These are often referred to as “stab” readings. Installation of coupons should be considered to ensure proper measurements. Attenuation models may be used to predict the potential distribution between successive measurement points.

NOTE For concrete weight-coated pipelines where the coating is in good condition, this technique can be very limited as contact readings to anodes do not provide information on protection level.

One survey method, which overcomes the problem of being unable to contact the pipe directly, uses fixed reference electrode arrays at a known distance from the pipeline. The arrays shall be mounted on the ROV with two or more reference electrodes at measurable distances apart. The ROV shall move along the pipeline at a fixed distance, and shall measure electrical field gradients around the pipe due to the CP current in the seawater. Using computer software, these measurements can be converted into pipe-to-seawater potentials and the potential profile along the pipeline can be determined. Electric field gradient measurements can be used for assessing current density levels on anodes and pipeline, and for locating coating defects.

A less accurate survey method utilizes a submerged sensor or “fish”, towed along by a surface vessel. With this technique, electrical contact is made to the pipeline via a trailing wire connected to the pipeline at the landfall or the riser. The surface vessel shall follow the route of the pipeline, towing the “fish” behind it. The potential of the pipeline shall be measured continuously with respect to the reference electrode

mounted on the “fish”. The accuracy of the potential measurements is determined by the position of the “fish” with respect to the pipe, and benefits therefore are limited.

If divers or ROVs are performing other activities to pipelines, such as completing tie-ins, inspecting spans, carrying out repairs or re-burial, opportunity should be taken to gather CP data.

If an insulated pipeline system has become waterlogged, cathodic protection cannot be very effective. Additional means of assessing possible corrosion of the pipeline (e.g. intelligent pigs) should be considered and a survey plan developed accordingly.

D.7 Inspection of impressed-current system components

Sources of impressed current shall be checked six times per calendar year at intervals not exceeding 2,5 months. The voltage and current output shall be measured, and shall be close to the values obtained upon completion of commissioning.

Reverse-current switches, diodes and interference bonds, whose failure would jeopardize pipeline protection, shall be inspected for proper functioning six times per calendar year at intervals not exceeding 2,5 months.

Impressed-current system facilities shall be inspected once each calendar year, at intervals not exceeding 15 months, to minimize in-service failures. These inspections should include a check for electrical short-circuiting, grounding connections, meter accuracy, efficiency and circuit resistance.

The effectiveness of the electrical isolating devices and continuity bonds shall be evaluated during the periodic surveys.

D.8 Safety

Relevant statutory safety regulations shall be followed where divers work on pipelines protected by impressed-current CP systems. The main dangers can arise from any CP system, but those generally limited to impressed-current systems are physical obstruction, electric shock and flammable, toxic or pressure-energy hazards.

The d.c. supply of anodes shall be switched off during diving operations not directly related to CP systems and any diving inspections carried out close to impressed-current anodes. However, diving CP inspections may be performed with the impressed-current system in operation, provided all relevant safety regulations and precautions are observed.

D.9 Documentation

Inspection reports shall contain measurement procedures, locations, and results and data from installed on-line monitoring systems.

Historic data of periodic inspections and on-line monitoring should be kept such that long-term trends become apparent and can be analysed. This can be achieved using dedicated software.

An inspection survey report shall be provided when the data are processed and interpreted, and should include the following:

- description of the operations performed;
- technical characteristics and operating parameters of the monitoring equipment used;
- any corrections applied to the records;
- plotted graphs of pipe potential along the pipeline;
- measured field gradients (if required);

ISO 15589-2:2012(E)

- measured resistivity values (if required);
- original recordings on paper and on magnetic or optical storage medium;
- comparison of the recorded data with those recorded at previous surveys.

Annex E (normative)

Laboratory testing of galvanic anodes for quality control

E.1 General

This laboratory test procedure should be used for quality control of aluminium and zinc materials during production of galvanic anodes. The results should not be used for CP design because the electrochemical data obtained from short-term testing may not be representative of long-term performance.

E.2 Sampling and preparation of test specimens

Unless otherwise specified, quality control of electrochemical properties (anode potential and electrochemical capacity) shall be carried out for each 15 t of anodes produced.

Specimens for testing may be cut from a production anode from each batch, or cast separately.

NOTE Cast specimens are likely to produce the most representative results.

Test specimens shall be cylindrical with a diameter of $10 \text{ mm} \pm 1 \text{ mm}$ and a length of $50 \text{ mm} \pm 5 \text{ mm}$. Identification marking shall be maintained throughout preparation and testing.

A hole approximately 2 mm in diameter shall be drilled through the test specimen, tapped at one end and connected to a titanium support rod which shall have an electrically insulating coating on all areas to be exposed to the test solution.

Prior to exposure, the test specimens shall be rinsed in tap water, dried using ethanol or equivalent and weighed to the nearest 0,1 mg.

After mounting on the support rod, the specimen ends shall be coated with a suitable sealing compound such as polychloroprene glue or silicone rubber.

E.3 Equipment and experimental procedure

The testing solution shall be natural seawater or artificial seawater in accordance with ASTM D1141. A minimum of 10 l of test solution per specimen shall be used. The test solution shall be continuously purged with air, maintained at a temperature of $20 \text{ }^\circ\text{C} \pm 3 \text{ }^\circ\text{C}$ and shall not be changed for the duration of the test.

Each specimen shall be suspended in the centre of an uncoated cylindrical steel container or pipe segment, the wetted surface shall be at least 20 times the anode specimen area, i.e. minimum 400 cm^2 .

Galvanostatic control shall be carried out by means of a constant d.c. current source. The specimen and the steel cathode shall be coupled to the positive and negative terminals respectively. Multiple testing cells may be connected in series to one d.c. source. A copper coulometer current integrator or an electronic device, capable of determining the total discharged current to an accuracy of $\pm 2 \%$, shall be installed into the circuit containing one or more test cells arranged in series.

The current through the cell(s) shall be adjusted to provide anode current densities, based on the initial exposed specimen surface area, in accordance with the following scheme:

- Day 1: $1,5 \text{ mA/cm}^2$
- Day 2: $0,4 \text{ mA/cm}^2$

ISO 15589-2:2012(E)

- Day 3: 4,0 mA/cm²
- Day 4: 1,5 mA/cm²

The current density shall be controlled to an accuracy of $\pm 0,1$ mA/cm² and shall be maintained for a period of 24 h \pm 1 h for a total testing time of 96 h \pm 4 h.

At the end of each test period, the anode potential shall be measured at three positions per specimen. A standard reference electrode with an electrolyte bridge (e.g. a Luggin capillary) shall be applied. The tip of the bridge shall be positioned within 1 mm of the specimen surface, which shall not be cleaned of corrosion products prior to taking measurements.

After completion of a full test period, the specimens shall be cleaned of corrosion products. Aluminium specimens shall be cleaned for 10 min at 80 °C in a solution containing 20 g chromium trioxide and 30 ml concentrated phosphoric acid per litre of water. Zinc specimens shall be immersed for 2 h in a saturated ammonium chloride solution at ambient temperature. The test specimens shall be rinsed in tap water, dried in ethanol, or equivalent, and weighed to the nearest 0,1 mg. The electrochemical anode capacity shall be calculated using Equation (E.1):

$$\varepsilon = Q/\Delta m \quad (E.1)$$

where

- ε is the electrochemical capacity, in ampere hours per kilogram;
- Q is the total electric charge, in ampere hours;
- Δm is the specimen mass loss, in kilograms.

E.4 Acceptance criteria and retesting

In case of failure to meet the specified requirements, retests may be carried out on three specimens from each heat that failed to meet the requirements. Failure of any of these three specimens to meet the specified requirements should lead to rejection of all anodes from the heat(s) involved or to other actions being taken as agreed prior to fabrication.

E.5 Documentation

A test report containing the following shall be prepared:

- a) data for the test material, including heat number, chemical composition and casting date;
- b) specimen preparation, test equipment and procedures;
- c) recorded potentials, presented in a tabular form;
- d) anode mass loss and total current charge;
- e) calculated anode electrochemical capacity.

Annex F (informative)

Interference

F.1 General

This annex provides guidance for the detection and control of a.c. and d.c. interference currents for pipelines.

Corrosion caused by interference current on submerged pipelines differs from other causes of corrosion damage in that the current which causes the corrosion has a source foreign to the affected pipeline. Typical sources of interfering currents are d.c. electrical power cables, welding, direct electrical heating systems and foreign impressed-current systems.

Galvanic anode systems do not cause interference-current problems on foreign neighbouring structures.

Detrimental effects of interference currents occur at locations where the currents are transferred between the affected pipeline and the electrolyte (seawater or seabed).

F.2 Control of interference currents

Tests should be conducted in areas where interference currents are suspected. The type of test depends on water depth and accessibility of the pipeline. Any one or a combination of the following test methods can be used:

- measurement of the pipe-to-electrolyte potentials with recording or indicating instruments, using field gradient or a similar continuous potential measurement technique;
- measurement of the variations in current output of the suspected source of interference current, and correlation with measurements obtained with the method described above.

NOTE Interference current corrosion on a submerged pipeline can be caused by a neighbouring foreign structure not electrically bonded to the subject pipeline. Current from such foreign structure finds its way onto the pipeline via low-resistance paths in the seawater. Accelerated corrosion of the pipeline can occur at locations where the interference current discharges into the electrolyte from the pipeline and returns to the foreign structure.

F.3 Interference from direct current

F.3.1 Measurements

In areas where d.c. interference currents are suspected, appropriate tests shall be conducted. Any one or any combination of the following test methods should be employed by measuring:

- pipeline potentials, using recording or indicating instruments;
- current density on coupons;
- current flowing on the pipeline, using recording or indicating instruments;
- variations in current output of the suspected source of interference current, and correlation with measurements obtained as above.

The tests should be carried out for a period sufficient for assessing the time dependence of the interference level. Time dependence is dictated by the type of interference phenomenon being investigated.

Interference with other submerged pipelines or installations should be measured after the CP system is energized. These interference tests should be conducted as follows:

- measure the pipeline-to-seawater potential on both the foreign pipeline and the subject pipeline while the relevant sources of CP current that can cause interference are simultaneously interrupted;
- measure the pipeline-to-seawater potential at the foreign pipeline or installation while the CP stations on both the foreign pipeline and the subject pipeline are energized.

The mean change in potential at any part of a foreign pipeline or installation due to interference should not cause the potential on the foreign pipeline to be outside the protection limits given in Clause 6. If interference results in the CP criteria not being met, remedial action shall be taken to reduce the interference to an acceptable level.

F.3.2 General methods for resolving d.c. interference corrosion problems

The following general methods should be considered to resolve interference problems on pipelines or other submerged structures:

- prevention of pick-up or limitation of flow of interfering current through a pipeline;
- removal of detrimental effects of interfering current from a pipeline by means of a metallic conductor between the pipeline and the return (negative) side of the interfering-current source;
- counteraction of the interfering-current effect by means of additional CP on the affected pipeline;
- removal, relocation or readjusting of interfering-current source.

F.4 Interference from alternating current

High voltage a.c. sources, such as power cables and pipeline electrical-resistance heating systems, can result in a.c. interference on the pipeline. The magnitude of this interference depends on the

- proximity of the a.c. source,
- a.c. voltage level,
- a.c. current level,
- number and location of galvanic anodes,
- pipeline coating quality, and
- conductivity of the steel and the seawater.

A.C. interference on pipelines, although rare on offshore pipelines, can cause safety and corrosion issues if not mitigated effectively.

Annex G (informative)

Pipeline design for CP

G.1 General

This annex covers design and installation features which should be addressed when specifying or designing external corrosion-control systems for offshore pipelines and pipeline risers. It includes specific recommendations for pipelines and risers of various types and installed by different methods.

Pipelines and risers can be addressed as separate entities due to the differences in environmental exposure. The pipeline is normally fully submerged and/or buried in the seabed, whereas the riser may have sections that are buried, submerged, and exposed to tidal, splash and atmospheric zones.

G.2 Pipeline installation methods

G.2.1 General

Water depth, length and diameter of the pipeline, geographic location and economics are the main factors that drive selection of the pipeline installation method. The method selected should be contained in the CP methodology. The installation method should not damage external protective coatings or CP hardware. The installation of a corrosion-control system completed on the lay barge should not adversely affect pipeline installation rate.

G.2.2 S-lay

Galvanic anodes can be pre-installed onto the individual pipe lengths onshore, or attached offshore if this does not affect the pipe lay rate. The anodes or anode connection wires should not be damaged as the pipe moves across the stinger. The selection of field joint coatings, installed offshore after successive pipe lengths are welded together, and coating breakdown factors (see 7.5) should take into consideration the achievable field-joint coating quality.

The most common installation method is for pipe lengths to be joined together, usually by welding, on the pipe lay vessel just prior to installation. The pipe is then fed horizontally from the back of the pipe lay vessel over a stinger as the lay vessel moves forward, the pipeline adopting an S-shape between the seabed and the vessel as it is progressively laid along the seabed. The quality of the field joint coating can be a large factor in the overall initial damage to pipeline coating.

G.2.3 J-lay

The J-lay method is commonly used in deeper waters.

This method involves deployment of the pipe vertically from a J-lay frame, usually located at the rear of the pipe lay vessel. In this method the pipe is subjected to high levels of tension. Prior to the lay, pipeline subsections (usually as quadruple joints) are formed on the deck of the pipe lay vessel and then raised up vertically within the J-lay frame. Special J-lay collars are welded to the pipe at intervals and used to enable the lay vessel to support the weight of the pipe as it is lowered vertically from the lay vessel.

These collars, which often serve also as pipeline-buckle arresters, can be used as galvanic anode installation sites. Bracelet anodes can be pre-installed onshore or can be installed on the quadruple joints offshore. Field joint coatings can be applied to the quadruple joints on the deck of the vessel, but the final "tie-ins" should be applied while the pipe is in a vertical aspect in the J-lay frame.

G.2.4 Reel lay

With the reel-lay method, the individual pipe lengths are pre-welded onshore into long sections. The field joints are coated onshore and the pipe is then reeled up onto a large spool on the pipe lay vessel.

Spacer pads should be deployed between the pipe coils on the reel to minimize coating damage due to pipe-to-pipe contact. Bracelet anodes should not be installed onshore, due to the high stresses introduced in the pipe during the reeling process.

During pipe lay, the pipe is unreeled while being held in tension and deployed, usually over a stinger, in an S-lay configuration. The pipe passes through a series of rollers on the pipe lay vessel which serve to straighten the pipe coming off the reel. A major advantage of this pipe lay method is the speed at which the pipeline can be installed.

Anode installation, which is accomplished on the lay vessel as the pipe is unreeled, should not adversely affect the pipeline installation process. Bracelet anodes and/or anode connection details should be robust enough to withstand the forces exerted on the pipe as it goes over the stinger.

G.2.5 Bottom-tow installation

This method of pipeline installation is only relevant for short pipelines of the order of a few kilometres in length. The pipeline is completely prefabricated onshore at a coastal site (including field-joint coating and galvanic anode installation). The pipeline is then towed out from the coastal site and along the seabed to the installation site.

Abrasion-resistant coatings for the pipe and the field joints should be used, and special precautions taken in the design of anodes. The anode attachment details should provide mechanical stability, reduced drag resistance and minimal snagging risks.

G.2.6 Controlled-depth tow

This method eliminates most of the concerns associated with bottom-tow installation, but the anode weight and distribution shall be taken into account in the buoyancy calculations.

The control-depth tow method is similar to the bottom-tow method, except that the pipeline is rendered buoyant, usually by dewatering and sealing the pipe and adding temporary buoyancy modules at intervals. Flexible weights (usually chains), hung from the pipeline at intervals, offset this buoyancy and allow the pipeline to float at a controlled depth above the seabed suspended between two vessels. The pipeline is towed to the desired location and lowered into place.

G.3 Offshore pipeline and riser types

G.3.1 Pipelines

G.3.1.1 Conventional pipelines

Conventional pipelines can be installed with or without concrete weight coating. They are either buried, open-trenched, or laid on the seabed. They are usually protected with galvanic bracelet anodes, remote galvanic anodes or impressed-current systems, the latter being located at one or both ends of the pipeline.

G.3.1.2 Thermally insulated pipelines

Thermal insulation can be required to prevent the temperature of the pipeline contents from falling below the point at which hydrates or paraffins can form and restrict fluid flow. There are two main types of pipeline thermal-insulation system: either several millimetres of a thick robust thermally insulating coating applied directly onto the pipeline externals, or a pipe-in-pipe system, in which the annular space between the inner and outer pipe is filled with an insulating material. In the pipe-in-pipe system, the outer pipe is fully sealed to ensure that the insulation remains dry. Externally applied thermally insulating

coatings are usually polypropylene- or polyurethane-based. Acceptably low heat transfer properties can be achieved by utilizing either syntactic or foamed formulations, or layers of both.

Different CP arrangements can include

- bracelet anodes directly connected to the pipeline,
- bracelet anodes clamped around the outside of the insulating coating with cable connections through the insulation to the steel,
- galvanic anodes installed remotely from the pipeline,
- an impressed-current system,
- thermally sprayed aluminium applied under the insulation.

Bracelet anodes directly attached to the pipe can provide a heat sink and reduce the overall effectiveness of the insulation system. The effects of elevated operating temperature shall be considered in the CP design.

For bracelet anodes clamped around the outside of the coating with cable connections through the insulation to the steel, there is risk of the anodes being moved during the laying process. In such cases, the use of anode-to-insulation transition tapers and disproportionately long connection cables should be considered. Four cables, two for each half-bracelet with the leads attached in longitudinally opposite directions, should be used for such electrical connections. Increased risk to the integrity of the insulation at cable penetrations should be considered.

G.3.1.3 Pipe-in-pipe systems

For pipe-in-pipe systems, thermally insulating materials with much lower thermal conductivities and poorer resistance to water ingress compared to externally applied thermal-insulation systems are used. A protective coating should be applied to the inner pipe before assembly in order to protect the pipe should water enter the outer pipe at some time in the life of the pipeline.

The external surface of the outer pipe should be treated for corrosion protection just as a conventional offshore pipeline.

G.3.1.4 Pipeline bundles

These systems comprise a number of small-diameter pipelines bundled together, often including electrical cables, and installed by the tow method. Dielectric spacers should be provided between the lines in the bundle. These spacers should not adversely affect the spread of protection or inflict damage on the pipe coating systems during construction or bundle installation.

Locating all of the anodes on one pipeline for the protection of all pipelines in the entire bundle may be considered. If this is the case, adequately spaced interpipeline electrical bonds shall be provided to ensure adequate electrical continuity on every pipeline.

G.3.1.5 Flexible pipelines

Flexible pipelines are often deployed as short tie-ins between subsea assemblies and conventional pipelines. If they are entirely of metallic construction, electrical continuity between the flexible pipeline, the conventional pipeline systems and the subsea assemblies should be ensured.

For flexible pipeline systems comprised of concentric non-metallic and metallic sheaths with a thick outer non-metallic layer which run between the metallic couplings or joints, anodes should be located at the metallic couplings or joints.

G.3.2 Risers

G.3.2.1 Standard fixed (static) risers

This type of riser can be connected to the end of the pipeline via a spool piece, with flanged joints at either end. It is usually clamped to the host structure at various elevations. Galvanic anodes may be installed on the riser, or CP provided from the structure or the pipeline.

If electrical isolation of the riser and pipeline from the structure is required, then all of the riser clamps shall be fitted with a dielectric liner of neoprene rubber or similar material. This can be installed at either the pipe-to-clamp interface or the clamp-to-structure interface. If the clamp is electrically isolated from both the riser and the structure, dedicated anodes should be installed on the clamps.

If an isolating flange or joint is installed at the riser, test leads should be provided from either side of the joint, terminating in a weatherproof test box located at an accessible site.

G.3.2.2 Pull tubes (J-tubes)

On fixed and floating offshore platforms in deep water, pre-installed J-tubes can be used to facilitate riser installation. J-tubes are used for pulling the riser into the platform and for mechanical protection of the pipeline risers during the lifespan of the platform. After pull-in and during subsequent operation, it is difficult to verify the effectiveness of the corrosion protection of the section of the pipeline riser within the J-tube.

Risers installed in this way should be protected with a high-quality, abrasion-resistant coating system to minimize damage to the coating during pull-in. However, adequate allowance should be made for the likelihood of coating damage when determining the CP requirements for the section of the riser within the J-tube. Other corrosion-control measures, such as inhibition, may be applicable for the annular space between the J-tube and the riser.

If galvanic anodes are used to protect the lower internals of the J-tube, the anodes should be mounted at the 6 o'clock position in order not to interfere with the riser during pull-in operation.

G.3.2.3 Steel catenary risers

Steel catenary risers can be used to connect deepwater pipelines to floating production units. The riser is suspended from the production platform near the surface of the water and hangs from the platform with a pre-determined catenary to a point on the seabed where it touches the seabed. These riser systems can be subject to very high stresses in service. Certain components of the support detail can be fabricated from high-strength materials that are sensitive to CP under these highly stressed conditions. The extent of this sensitivity should be considered (see Table 1). Identification of any risks may preclude attaching anodes directly to the catenary section of the riser. Anodes may be located on the static section of the riser or the host structure above and/or on the pipeline below, in order to protect the catenary section. Potential attenuation modelling may be used to determine the spread of protection down the riser from different anode configurations and/or locations.

Steel catenary risers are often fitted with strakes to reduce the effects of vortex-induced vibration. CP may not be fully effective beneath the strakes, and this should be recognized in the selection of a suitable protective coating for these areas.

G.3.2.4 Flexible risers

These are normally of the same construction as the flexible pipe previously discussed (see G.3.1.5), and the same considerations apply.

G.4 Burial and stabilization

G.4.1 General

The decision whether or not to bury an offshore pipeline and/or how to stabilize it on the seabed is determined based on the fluid being conveyed, the operating temperature and any local regulations. The extent of burial and any measures used to stabilize the pipeline should be considered in the design and effectiveness of the CP system.

G.4.2 Burial conditions

G.4.2.1 Exposed

In this condition, the pipeline is initially laid on the seabed where it is exposed mainly to seawater and can be susceptible to in-service damage to coatings and anodes. This should be considered in the CP design, particularly in shallow waters in busy shipping areas.

If, for design purposes, there is no seabed movement in the area, the pipeline and anodes should both be considered as being 100 % exposed. If during the life of the pipeline there is evidence of seabed movement such that the anodes could be covered by sediment (and the pipeline remaining exposed or also becoming buried), this should be considered in the CP system design.

NOTE The worst case for CP design is pipeline which is 100 % exposed with the anodes 100 % buried; the best case design is pipeline which is 100 % buried and the anodes 100 % exposed. In partial-burial situations, the actual case lies somewhere between these extremes.

G.4.2.2 Open-trenched

In this condition, the pipe is laid into a pre-excavated trench and no attempt is made to bury it. The assumption is that this will protect the pipeline from mechanical damage, as the trench usually self-backfills with time. Such pipelines are normally given the same consideration as fully buried lines when designing the CP system, but this should be assessed taking into consideration local field experience with self-burial.

G.4.2.3 Trenched and filled

In this condition, the pipeline is intentionally buried, usually with the aid of a towed burial sled that buries and backfills the line in a single pass. If this method is to be used, it should be ensured that anodes do not provide a snagging point for towed-sled apparatus which normally straddles and moves along the pipeline. The use of fully moulded tapered anodes or those fitted with reinforced cast-on polyurethane tapers, to smooth the cross-sectional transition, are measures that should be considered in this case.

If there is likelihood of a buried pipeline becoming exposed, more anodes can be required. This should be considered in the design and, if recognized as a risk, the pipeline should be designed as an exposed pipeline.

G.4.3 Stabilization methods

G.4.3.1 Unstabilized pipeline

For pipelines without concrete coating, anodes should be installed on top of the corrosion coating. The method of anode attachment shall be sufficiently robust to withstand the pipe-laying process. Methods to avoid anode slippage can include the use of anodes with a tapered shape or with tapered end fittings on either side of the anode, as required for the pipe-laying process.

G.4.3.2 Weight-coated pipeline

The application of a reinforced concrete coating over the corrosion coating is standard procedure for some large-diameter subsea pipelines. The concrete reduces buoyancy and provides mechanical protection to the pipeline additional to that which can be gained by partial or total burial.

During galvanic anode installation, it should be ensured that the steel reinforcement in the concrete does not come into electrical contact with either the pipeline itself or the bracelet anodes, to avoid shielding of the protective current to the pipeline. Electrical continuity between the reinforcement and the pipe and/or the anodes can also impose a higher current demand on the pipeline anodes than allowed for in the CP design. If the weight-coated line is to be installed by the S-lay or J-lay method, the anodes should be inset within, or flush with, the concrete weight coating. Alternatively, the use of tapered anodes or reinforcing cast-on polyurethane tapers may be considered in order to smooth the cross-sectional transition and thus minimize damage to the anodes during the laying operation.

G.4.3.3 Rock dumping

Rock dumping involves the covering of an unburied pipeline with rocks. If this is the proposed method of stabilization, additional coating damage and loss of anodes can be expected, and the CP design should reflect this. The use of pre-fabricated flexible concrete mats is sometimes used instead of rock dumping to stabilize a pipeline. Some newer designs provide non-metallic soft coverings over the concrete to further reduce the risk of coating damage during installation. The mats can be lowered gently onto the pipeline in a controlled manner.

G.4.3.4 Pipeline anchors

Various types of pipeline anchor can be used in areas of high current flow, such as near large estuaries, and in certain arctic regions. The impact of these anchors on the CP design should be carefully evaluated, especially if they include the use of steel pilings. If an excessive current drain to the anchors is predicted, the anchors should be provided with a CP system independent of the pipeline system.

G.5 Pipeline crossings and subsea connections

G.5.1 Crossings

Interference can occur between the CP systems at subsea pipeline crossings. If both pipelines are protected by galvanic anodes, it is normal to provide separation between the two pipelines at the crossing point.

A separation of 0,3 m is normally adequate, but smaller separation distances may be acceptable if it can be demonstrated that CP interference between the lines is insignificant.

The risk of seabed or pipe movement with time should be compensated for by the introduction of a physical separation barrier at the crossing point. The barrier can be a concrete mat, a rubber mat or sandbags.

G.5.2 Subsea connections

At subsea connections between two pipeline systems, it should be ensured that no significant interference occurs between the CP systems on the two pipelines.

If the two systems are directly connected, all the relevant details of the CP systems should be considered, such that neither CP system causes an undue drain on the other CP system.

If the two systems are electrically isolated, the condition of the isolation joint and of the anodes close to the isolation joint should be periodically verified. The possibility of interference between the two systems should be considered, e.g. in the case of one of the lines having an impressed-current system and the other line having a galvanic system.

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