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

Part 1:
On-land pipelines

*Industries du pétrole et du gaz naturel — Protection cathodique des
systèmes de transport par conduites —*

Partie 1: Conduites terrestres

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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 15589-1 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*.

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

External corrosion control in general is covered by ISO 13623.

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 inhibit alternative equipment or engineering solutions to be used for the individual application. This may be particularly applicable where there is innovative or developing technology. Where an alternative is offered, any variations from this part of ISO 15589 should be identified.

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Petroleum and natural gas industries — Cathodic protection of pipeline transportation 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, fabrication, installation, commissioning, operation, inspection and maintenance of cathodic protection systems for on-land pipelines, as defined in ISO 13623, for the petroleum and natural gas industries.

This part of ISO 15589 is applicable to buried carbon steel and stainless steel pipelines on land. It can also apply to landfalls of offshore pipeline sections protected by onshore-based cathodic protection installations.

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

NOTE Special conditions sometimes exist where cathodic protection is ineffective or only partially effective. Such conditions can include elevated temperatures, disbonded coatings, thermal-insulating coatings, shielding, bacterial attack and unusual contaminants in the electrolyte.

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

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

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

ASTM G 97¹⁾, *Standard test method for laboratory evaluation of magnesium sacrificial anode test specimens for underground applications*

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

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**
material with a low resistivity, which may be moisture-retaining, immediately surrounding a buried anode, for the purpose of decreasing the effective resistance between the anode and the electrolyte and to prevent anode polarization
- 3.2 bond**
metal conductor, usually copper, connecting two points on the same or on different structures, usually with the intention of providing electrical continuity between the points
- 3.3 cathodic protection system**
system consisting of a d.c. current source and an anode in order to provide protective current to a metallic structure
- 3.4 coupon**
representative metal sample of known surface area used to quantify the extent of corrosion or the effectiveness of applied cathodic protection
- 3.5 d.c. decoupling device**
protective device that conducts electricity when predetermined threshold voltage levels are exceeded
- EXAMPLE Polarization cells, spark gaps and diode assemblies.
- 3.6 drain point**
location of the negative cable connection to the protected structure through which the protective current returns to its source
- 3.7 galvanic anode**
electrode that provides current for cathodic protection by means of galvanic action
- 3.8 groundbed**
system of buried or immersed galvanic or impressed-current anodes
- 3.9 impressed-current anode**
electrode that provides current for cathodic protection by means of impressed current
- 3.10 impressed-current station**
station containing the equipment which provides cathodic protection by means of impressed current
- 3.11 impressed-current system**
system which provides cathodic protection by means of impressed current

3.12**instant-on potential**

structure-to-electrolyte potential measured immediately after turning on all sources of applied cathodic protection current

3.13**intensive measurement technique**

technique which simultaneously measures pipe-to-electrolyte potentials and associated perpendicular potential gradients

NOTE The intensive measurement technique identifies coating defects and enables calculation of IR-free potentials at the defects.

3.14**IR drop**

voltage, due to any current, developed between two points in the metallic path or in the lateral gradient in an electrolyte such as the soil, measured between a reference electrode and the metal of the pipe, in accordance with Ohm's Law

3.15**IR-free potential
polarized potential**

structure-to-electrolyte potential measured without the voltage error caused by the IR drop from the protection current or any other current

3.16**isolating joint**

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

EXAMPLE Monobloc isolating joint, isolating flange, isolating coupling.

3.17**monitoring station
test post**

station where measuring and test facilities for the buried pipeline are located

3.18**on-potential**

structure-to-soil potential measured while the cathodic protection system is continuously operating

3.19**off potential
instant-off potential**

structure-to-electrolyte potential measured immediately after interruption off all sources of applied cathodic protection current

NOTE This potential is normally measured immediately after the cathodic protection system is switched off and the applied electrical current stops flowing to the bare steel surface, but before polarization has decreased.

3.20**protection potential**

structure-to-electrolyte potential for which the metal corrosion rate is insignificant

3.21**reference electrode**

electrode whose open circuit potential is constant under similar conditions of measurement, used to measure the structure-to-electrolyte potential

3.22

remote earth

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

NOTE This condition generally prevails outside the zone of influence of an earth electrode, an earthing system, an impressed-current groundbed or a protected structure.

3.23

stray current

current in the path other than the protective current under consideration

4 Symbols and abbreviations

- a.c. alternating current
- CP cathodic protection
- CSE copper–copper sulfate (saturated) reference electrode
- d.c. direct current
- SCC stress corrosion cracking
- SCE calomel reference electrode

5 Design requirements

5.1 General

For new construction projects, the design of the CP system shall be part of the total pipeline design and corrosion management. The details of the pipeline isolation (e.g. location of isolating joints) and the protective coating system shall be included.

Design, fabrication, installation, operation and maintenance of CP systems shall be carried out by experienced and qualified personnel.

5.2 Design information

The following technical information shall be collected and considered when designing a CP system:

- detailed information on the pipeline to be protected, e.g. length, diameter, wall thickness, type and grade of material, protective coating, operating temperature profile, design pressure;
- products to be transported;
- the required design life of the CP system;
- relevant drawings of the pipeline route, showing existing CP systems, existing foreign structures/pipelines etc.;
- environmental operating conditions for the CP equipment;
- topographical details and soil conditions, including soil resistivity;

- climatic conditions, e.g. frozen soil;
- the possibility of telluric current activity;
- location, route and rating of high-voltage overhead or buried power lines;
- valves and regulating station locations;
- water, railway and road crossings;
- casing pipes that will remain after construction;
- types of pipeline bedding material;
- types and locations of isolating joints;
- characteristics of neighbouring a.c. and d.c. traction systems (e.g. electrical substations and their operating voltages and polarities) and other interference-current sources;
- types and locations of earthing systems;
- availability of power supply.

The following information should be considered in the design of the pipeline CP system:

- soil pH, and the presence of bacteria which can cause corrosion;
- types and locations of neighbouring telemetry systems which can be used for remote monitoring.

5.3 Criteria for CP

5.3.1 General

The metal-to-electrolyte potential at which the corrosion rate is less than 0,01 mm per year is the protection potential, E_p . This corrosion rate is sufficiently low so that corrosion will be within acceptable limits for the design life. The criterion for CP is therefore

$$E \leq E_p$$

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

The protection potential criterion applies at the metal/electrolyte interface, i.e. a potential which is free from the IR drop in the corrosive environment (IR-free potential/polarized potential).

Some metals can be subject to hydrogen embrittlement at very negative potentials, and coating damage can also increase at very negative potentials. For such metals, the potential shall not be more negative than a limiting critical potential E_l . In such cases, the criterion for CP is

$$E_l \leq E \leq E_p$$

5.3.2 Protection criteria

5.3.2.1 The CP system shall be capable of polarizing all parts of the buried pipeline to potentials more negative than -850 mV referred to CSE, and to maintain such potentials throughout the design life of the pipeline. These potentials are those which exist at the metal-to-environment interface, i.e. the polarized potentials.

To prevent damage to the coating, the limiting critical potential should not be more negative than $-1\,200$ mV referred to CSE, to avoid the detrimental effects of hydrogen production and/or a high pH at the metal surface.

For high strength steels (specified minimum yield strength greater than 550 MPa) and corrosion-resistant alloys such as martensitic and duplex stainless steels, the limiting critical potential shall be determined with respect to the detrimental effects in the material due to hydrogen formation at the metal surface. Stainless steels and other corrosion-resistant alloys generally need protection potentials more positive than -850 mV referred to CSE; however, for most practical applications this value can be used.

For pipelines operating in anaerobic soils and where there are known, or suspected, significant quantities of sulfate-reducing bacteria (SRB) and/or other bacteria having detrimental effects on pipeline steels, potentials more negative than -950 mV referred to CSE should be used to control external corrosion.

For pipelines operating in soils with very high resistivity, a protection potential more positive than -850 mV referred to CSE may be considered, e.g. as follows:

- -750 mV for $100 < \rho < 1\,000$;
- -650 mV for $\rho \geq 1\,000$

where ρ is the soil resistivity, expressed in ohm metres.

As an alternative to the protection potentials given above, a minimum of 100 mV of cathodic polarization between the pipeline surface and a reference electrode contacting the electrolyte may be used. The formation or decay of polarization shall be measured in accordance with A.2.3.

5.3.2.2 The application of the 100 mV polarization criterion shall be avoided at higher operating temperatures, in SRB-containing soils, or with interference currents, equalizing currents and telluric currents. The conditions should be characterized prior to using this criterion. Furthermore, the criteria shall not be used in case of pipelines connected to or consisting of mixed metal components

5.3.2.3 Under certain conditions, pipelines suffer from high-pH SCC in the potential range -650 mV to -750 mV, and this shall be considered when using protective potentials more positive than -850 mV.

5.3.2.4 Care should be exercised in the use of all protection criteria where the pipeline is electrically continuous with components manufactured from metals more noble than carbon steel, such as copper earthing systems.

5.3.2.5 For pipelines operating at temperatures above 40 °C, the above values may not provide adequate protection potential. In these cases, alternative criteria shall be verified and applied.

5.3.3 Measurements of protection potentials

Measurement techniques shall be in accordance with Annex A.

Other practical reference electrodes to CSE may be used for the various criteria provided that their properties are reliable and documented.

If a.c. interference is present on a pipeline, a.c. corrosion can occur even though the protection potential is achieved (see Annex B).

5.4 Predesign investigations

A site survey shall be carried out before preparing the pipeline CP design. Information obtained during previous site surveys relevant to the proposed pipeline route may be used provided that the date and source of such surveys are documented. If the area to be surveyed is affected by seasonal changes, these shall be taken into account and the most severe conditions with respect to the soil conditions shall be used for the design.

The survey report shall contain the design information specified in 5.2.

Representative soil resistivity values should be obtained at pipeline depth along the route of the pipeline, and shall be obtained at various depths at prospective locations for anode groundbeds. The number of measurements should be based on local soil conditions. If there are changes in soil characteristics, more measurements shall be taken.

If corrosive conditions are anticipated due to bacterial activity, appropriate action shall be taken which might include chemical and bacterial analyses of the soil. This requirement shall be extended to the imported soil used for pipeline trench construction.

Possible sources of detrimental d.c. and a.c. interference currents shall be investigated, and the design shall include measures to mitigate the effect of such currents. Annex B shall apply with respect to the detection and control of interference currents.

Locations where high-voltage a.c. transmission lines or a.c.-powered train systems cross, or run parallel to, the pipeline shall be identified.

5.5 Electrical isolation

Isolating joints should be installed above ground whenever possible at both extremities of a pipeline, and should also be considered at the following locations:

- at connections to branch lines;
- between pipeline sections with different external coating systems;
- between pipeline sections running in different types of electrolyte (e.g. at river crossings);
- in areas of high telluric activity;
- on pipeline sections which are differently affected by a.c. or d.c. interference currents;
- between cathodically-protected pipelines and non-protected facilities.

Monobloc isolating joints should be used wherever possible. Each isolating joint/isolating flange should be provided with test facilities.

Safety-earthing and instrument-earthing shall be mutually compatible with the CP system. In areas where there could be an unacceptable risk of high voltages on the pipeline exceeding the joint's electrical capacity, e.g. caused by nearby power systems or lightning, the isolating joints or flanges shall be protected using electrical earthing or surge arrestors.

The design, materials, dimensions and construction of the isolating joints shall meet the design requirements of ISO 13623.

If the pipeline is transporting any fluids that are electrically conductive, the isolating joints shall be internally coated on the cathodic (most expected negative potential) side, for a length sufficient to avoid interference-current corrosion. All sealing, coating and insulation materials shall be resistant to the fluid transported.

The electrical resistance across isolating joints should be more than 10 M Ω measured at 1 000 V (d.c.) in dry air, before installation.

If the use of monobloc isolating joints is not practical, electrical isolation should be provided using isolating flange kits. Isolating flanges should be protected against ingress of dirt and moisture by the use of flange protectors or protective tape.

The pipeline under CP should be electrically isolated from common or plant earthing systems to avoid inadequate pipeline CP, unless measures are taken to ensure that adequate current is provided to the pipeline system to account for the galvanic effects of the other systems.

5.6 Electrical earthing

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

If electrical safety-earthing is required, this shall be made compatible with the CP system by installing polarization cells or diode circuits, suitably specified and rated for the purpose, in the earthing circuit or by installing separate earthing zinc or galvanized steel electrodes, buried in low-resistivity backfill and not in direct electrical continuity with other earthing systems.

If earthing is to be installed to mitigate the effect of a.c.-induced voltages on the pipeline, this should be done at the locations where the anticipated or measured voltages to ground are highest, and where the pipeline is exposed and can be touched by personnel.

The requirements for detection and control of electrical interference are contained in Annex B.

5.7 Electrical continuity

Under certain circumstances it might be necessary to bond across isolating devices for measurement or other purposes. If electrical continuity is to be established permanently, the bonding should be done in a monitoring station.

If CP is to be applied on non-welded pipelines, the continuity of the pipeline shall be ensured. This shall be done by installing permanent bonds across the high-resistance mechanical connectors, using suitable attachment methods. The continuity of non-welded pipelines shall be checked by carrying out resistance and potential measurements, see Annex A.

5.8 Current requirements

For new pipelines, the total current demand, I_{tot} , shall be determined by evaluating the design parameters and/or from previous experience with similar systems, using Equation (1):

$$I_{\text{tot}} = J \cdot F_c \cdot 2\pi r L \quad (1)$$

where:

- J is the design electric current density for bare steel, expressed in milliamperes per square metre;
- F_c is the coating breakdown factor, dimensionless;
- r is the outer radius of the pipeline, expressed in metres;
- L is the length of pipeline, expressed in metres.

Table 1 give values for the combined effects of design current density and coating breakdown that can be used if relevant previous experience is not available. The coating breakdown factor, F_c , includes the effects of factory coating and a compatible field-joint coating.

To determine the current demand for existing pipelines, where the actual condition of the applied coating is unknown, a current drainage test should be carried out.

Table 1 — Design current densities for coated pipe, ($J \cdot F_c$) in Equation (1), for steel in soils with various pipeline coatings to be used in the design of CP systems for operating temperatures ≤ 30 °C

Pipeline coating	Design current density		
	mA/m ²		
	10-year design life	20-year design life	30-year design life
Asphalt/coal-tar enamel Cold-applied tape	0,4	0,6	0,8
Fusion-bonded epoxy Liquid epoxy	0,4	0,6	0,9
3-layer epoxy-polyethylene 3-layer epoxy-polypropylene	0,08	0,1	0,4

For a design life of more than 30 years, correspondingly greater factors should be used.

It is assumed that pipeline construction and operation is carried out in such a manner that coating damage is minimized.

For pipelines operating at elevated temperatures, the current density values shall be increased by 25 % for each 10 °C rise in operating temperature above 30 °C.

Alternative design current values may be used if reliable and properly documented.

Current density requirements also depend upon the oxygen content and resistivity of the soil.

The CP system can be designed so that the increasing current demand due to progressive coating deterioration is catered for by a phased installation of additional CP facilities. Pipeline attenuation calculations can be carried out to define the spacing between drain points and anodes.

Consideration should be given to the risk of the coating becoming disbonded during its service life and the resulting possibility for corrosion due to shielding of CP current. Typical examples where this could occur include excessively negative potentials (5.3.2) or cases of extreme soil stress.

5.9 Type of CP system and selection of sites

5.9.1 General

The CP should preferably be accomplished by installing impressed-current systems. Alternatively, the CP may be accomplished by the use of galvanic anodes, the limitations of which are given in Clause 7.

The following factors shall be taken into account for sites of impressed-current CP systems:

- availability of a power supply;
- soil resistivity in the area of prospective groundbeds;
- possible current distribution problems and shielding effects by rock outcrops, high-resistivity soils, nearby structures, non-uniform geological features, etc;
- impact of the system on existing or future pipelines (including those owned by others) and other developments;
- good access for the installation of rectifiers and good access to monitoring stations;
- sufficient distance between the proposed groundbed sites and the pipeline to obtain adequate current distribution along the pipeline;

- existence of areas classified as hazardous areas along the pipeline route;
- existence of interference-current sources.

5.9.2 CP for thermally-insulated pipelines

Thermal insulation systems are generally defined as coating systems which 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 which provides both corrosion protection and thermal insulation.

The need for, and the type of, CP for thermally-insulated pipelines shall be subject to an additional evaluation taking into account the following.

- a) Thermally-insulating materials such as polyurethane foam have an extremely high electrical resistance and it is likely that, even if they become waterlogged, attempts to cathodically protect the underlying steel pipe will be unsuccessful due to the shielding effect of the thermal insulation. Alternative corrosion control methods should be considered in such cases.
- b) The installation of a CP 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, which will lead to direct exposure of the pipe to the soil.
- c) If a CP system already exists on an adjoining, or nearby structure and has sufficient spare capacity, then it can be considered to bond in the insulated pipeline to this system.
- d) Thermal insulation prevents the natural earthing of high voltages induced by adjacent power lines, etc. If steps are not taken to earth the pipeline in the vicinity of the induced voltage, then these voltage changes can occur for considerable distances and can cause corrosion and/or be a safety hazard to personnel who make direct contact with the pipe.

CP potentials measured on thermally-insulated pipelines are usually not indicative of the potentials which exist at the metal-to-electrolyte interface beneath the coating. As such, these potentials should not be used to determine the effectiveness of the CP on the pipeline. In this case, some other method should be used to verify the integrity of the pipeline.

6 Impressed-current systems

6.1 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. Before specifying the d.c. voltage source, the following shall be taken into account:

- 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;
- need for the installation of a current interrupter;

- electrical and safety requirements for the equipment;
- need for a.c. and/or d.c. surge protection;
- need for environmental protection and housing;
- a.c. content of the d.c. output (acceptable ripple factor);
- identification and rating plate details.

NOTE High voltage gradients in the soil in the vicinity of groundbeds can be a hazard to animals and persons.

Generally, voltages higher than 50 V (rectifier output) should be avoided. If this is impossible, then the likely consequences with regard to safety shall be assessed.

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

6.2 Groundbeds

6.2.1 General

The groundbeds of an impressed-current CP system shall be of the deep-well or shallow type and shall be designed and located so as to satisfy the following.

- a) The mass and material quality shall be suitable for the specified design life of the CP system.
- b) The resistance to remote earth of each groundbed shall allow the maximum predicted current demand to be met at no more than 70 % of the voltage capacity of the d.c. source during the design life of the CP system. The calculation shall be carried out for the unused anode bed.
- c) Harmful interference on neighbouring buried structures shall be avoided.

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

- soil conditions and the variation in resistivity with depth;
- groundwater levels;
- any evidence of extreme changes in soil 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 soil resistivity data available.

The current output from anodes should be independently adjustable.

6.2.2 Deep-well groundbeds

Deep-well groundbeds should be considered where

- soil 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,
- 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 soil 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.

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 only provide 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 soil resistivity data corresponding to the depth at the mid point of the active length shall be used and the possibility of multi-layered soils with significantly different soil 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.

6.2.3 Shallow groundbeds

Shallow groundbeds should be considered where

- soil resistivities near the surface are 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,
- there is no risk of interference currents being generated on adjacent installations.

Shallow groundbed anodes shall be installed horizontally or vertically. In either case, the top of the conductive backfill shall be at least 1 m below ground level.

In the calculation of the groundbed resistance, the soil 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 soils with significantly different soil resistivities considered.

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

6.2.4 Impressed-current anodes and conductive backfill

Anode materials should be selected from the following list:

- high-silicon iron alloy, including chromium additions, in soils with high chloride content;
- magnetite;
- graphite;

- mixed-metal-oxide-coated titanium;
- platinized titanium/niobium;
- conductive polymers;
- steel.

Alternative materials may be used if their performance relevant to the specific operating conditions are reliable and documented.

The specific material, dimensions and mass shall deliver 125 % of the required anode current output required for meeting the specified design life of the CP system.

A carbonaceous or other conductive backfill material shall be used unless the soil conditions give a satisfactory groundbed resistance, the soil is homogeneous and uniform consumption of anodes is expected.

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

Use of continuous conductive polymer anodes should be considered, particularly for very high resistivity soils surrounding the pipeline.

6.3 Current output control and distribution

6.3.1 General

The impressed-current output should be controlled by the output voltage on the rectifier and corresponding potentials measured along the pipeline.

6.3.2 Current distribution for multiple pipelines

Where there is more than one pipeline to be cathodically protected, the current return from the pipelines should be independently adjustable. In such cases, the pipelines shall be isolated from each other and provided with an individual negative connection to the current source.

Resistors should be installed in the negative drains to balance the current to each of the adjacent pipelines individually. Each negative drain shall 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.

6.3.3 Automatic potential control

The d.c. voltage source can be provided with automatic potential control, which shall be linked to a permanent reference electrode buried close to the pipeline. Reference electrodes shall be regularly calibrated.

The potential measuring circuit shall have a minimum input resistance of 100 M Ω . The electronic control system shall have an accuracy of ± 10 mV and be provided with adjustable voltage- and current-limiting circuits and/or alarms to protect the pipeline against polarization outside the established criteria in the event that a reference electrode fails. A panel-mounted meter should be provided to enable the pipe-to-soil potential to be read.

6.3.4 Automatic current control

The d.c. voltage source can be provided with current control to set the current to the pipeline or the anode system.

Automatic current control alone shall not be used for setting current flow where soil moisture or other variations near the pipeline can cause potential variations.

7 Galvanic-anode systems

7.1 General

Galvanic-anode systems should be considered for small-diameter pipelines, or on short lengths of high-quality-coated larger diameter pipelines, in low resistivity soils, 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 will be impractical,
- for localized (hot-spot) protection to supplement impressed-current systems,
- where remote impressed-current systems cannot be provided,
- in the thaw-bulb at locations where the soil around the pipeline can freeze (permafrost),
- under thermal insulation on thermally insulated pipelines.

For galvanic-anode systems, the following shall apply.

- The resistivity of the soil or the anode backfill shall be sufficiently low for successful application of galvanic anodes;
- The selected type of anode shall be capable of continuously supplying the maximum current demand;
- The total mass of anode material shall be sufficient to supply the required current for the design life of the system.

Galvanic anodes shall be marked with the type of material (e.g. tradename), anode mass (without anode backfill) and melt 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 shall be considered.

7.2 Zinc anodes

A typical composition of zinc anodes is given in Table 2.

Table 2 — Typical chemical composition of the alloy used for zinc anodes

Element	Composition mass fraction, %	
	min.	max.
Cu	—	0,005
Al	0,10	0,50
Fe	—	0,005
Cd	—	0,07
Pb	—	0,006
Zn	Remainder	
The maximum amount of other elements shall be 0,02 % (mass fraction) each.		

Other alloys may be used provided the performance in similar soils is reliable and documented.

Zinc anodes should not be used if the resistivity of the electrolyte is higher than 30 $\Omega\cdot\text{m}$, unless the engineering evaluation or field test confirm that the design requirements can still be met.

7.3 Magnesium anodes

Magnesium anodes shall be performance-tested in accordance with ASTM G 97. The values obtained from the testing shall be the basis for the design of the system. A typical composition of magnesium anodes is given in Table 3.

Table 3 — Typical chemical composition of the standard alloy used for magnesium anodes

Element	Composition mass fraction, %	
	min.	max.
Cu	—	0,02
Al	5,3	6,7
Si	—	0,1
Fe	—	0,003
Mn	0,15	—
Ni	—	0,002
Zn	2,5	3,5
Mg	Remainder	
The maximum amount of other elements shall be 0,005 % (mass fraction) each.		

Other alloys may be used provided the performance in similar soils is reliable and documented.

Magnesium should not be used if the resistivity of the electrolyte is higher than 150 $\Omega\cdot\text{m}$ unless the engineering evaluation or field test confirm that the design requirements can be met.

7.4 Anode backfill

Anode backfill for galvanic anodes should consist of a mixture of gypsum, bentonite clay and sodium sulfate. The specific composition of the anode backfill shall be determined by the need to minimize resistivity and maximize moisture retention.

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

7.5 Cables and cable connections

Galvanic anode cables should be connected to the pipeline via a bond-box and link or shunt incorporated into the circuit inside the box.

8 Monitoring facilities

8.1 General

Monitoring facilities shall be installed along the pipeline route to ensure that CP is being applied in all areas.

8.2 Monitoring stations (test posts)

To monitor pipe-to-soil potentials, current and possible interferences, monitoring stations shall be installed at intervals not greater than 3 km along the pipeline. In urban or industrial areas, the intervals should not be greater than 1 km.

Monitoring stations shall also be installed at special features, such as

- crossings or parallelisms with a.c./d.c. traction systems,
- isolating joints,
- connection to earthing systems,
- metallic casings,
- bond connections to other pipelines or facilities,
- connections with coupons and grounding.

Monitoring stations should also be installed where the pipeline

- crosses other pipelines,
- crosses major roads and embankments (dykes),
- crosses railways and rivers,
- runs close to other structures.

If pipelines are running in parallel, but not in the same trench, each pipeline shall be provided with separate potential-monitoring facilities.

Generally, the monitoring stations should be installed above the pipeline.

From each monitoring station, at least two separate cables shall be attached to the pipeline. All cables shall be identified by colour-coding or tags.

8.3 Bonding to other pipelines

A bonding facility should be considered at crossings with other pipelines. It shall consist of two separate cables attached to each individual pipeline, terminating in a monitoring station with facilities to install direct or resistive bonds if required.

8.4 Test facilities at cased crossings

To detect contacts between a metallic casing and the carrier pipe, two test cables shall be installed on both ends of the casing and two test cables shall be installed on the pipeline at both ends of the casing.

All cables shall be terminated in a monitoring station.

8.5 Test facilities at isolating joints

A cable connection (consisting of two cables) shall be installed on each side of all isolating joints. All cables shall be separately terminated in a single monitoring station with facilities to install direct or resistive bonds and surge arrestors.

8.6 Drain-point test facilities

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

At the drain point, a monitoring station should be installed using a separate test cable connected to the pipeline, for the measurement of the drain point potential. A monitoring station is not required if the drain point is installed on an above-ground section of the pipeline.

8.7 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.

9 Special facilities

9.1 Temporary protection

If the installation and commissioning of the permanent CP system cannot be finalized for a period of six months after the pipeline is buried (or a shorter period if the corrosion risk is greater), a temporary CP system shall be installed. Such a system shall be designed to cover the pipeline construction period until the commissioning of the permanent CP system.

Anode connections should be constructed such that they can easily be connected and disconnected during and/or after commissioning of the permanent system.

Permanent monitoring facilities connected to the pipeline should be installed simultaneously with the pipeline to allow monitoring of the performance of the temporary system.

9.2 Protective casings

For effective CP, the use of pipeline casings should be discouraged. If their use is unavoidable, the casing shall be designed to cause minimal interference with, or shielding of, the CP. The pipeline inside the casing shall have a high-quality coating for protection against corrosion.

Steel casings shall be electrically insulated from the pipeline using non-metallic spacers, and should not be coated.

To minimize the risk of water entering and collecting in the casings, end seals and vent pipes should be installed. Alternatively, the space between the casing and the pipeline should be filled with a material with adequate long-term corrosion protection properties.

NOTE A bare-steel casing can conduct CP current to the pipeline. If an external coating is applied to a steel casing, this will not conduct CP current to the pipeline within the casing. Cathodic protection of the carrier pipe within the casing can be improved by earthing the casing using steel earthing rod(s).

For non-metallic casings (and coated steel casings, if used), CP should be provided to the pipeline inside the casing by installing galvanic anodes or impressed-current polymer anodes along the bottom of the pipe, together with a reference electrode inside the casing. The galvanic anodes should be attached to the pipeline via a cable in a monitoring station. The cable from the reference electrode should be run back into the monitoring station and terminated in a separate connection. For concrete casings, the CP current can pass through the concrete if it is sufficiently conductive and if there is no metallic contact between the reinforcement and the pipeline.

9.3 Parallel power lines or a.c. traction systems

If the pipeline runs parallel to, or crosses the route of, high-voltage power lines or a.c. traction systems, large a.c. voltages can be present on the pipeline due to electromagnetic induction or due to conduction of locally-earthed electrical faults. Any such effects shall be investigated and their likely impact upon the integrity of the pipeline and the safety of personnel shall be determined (see Annex B).

9.4 Lightning protection

To protect isolating joints and CP equipment in areas of lightning activity, lightning protection shall be installed. Surge arrestors (see 9.5) should be mounted across isolating joints and output terminals of d.c. voltage sources.

Such measures should take into account the need for potential equalization between the pipeline, anodes, power supplies, reference electrodes, etc. during lightning strikes.

9.5 Surge arrestors

Surge arrestors, to prevent elevated voltages from being present on pipelines due to faults in adjacent electrical power systems or to lightning strikes, should be of the spark-gap type and shall be designed as follows.

- The impulse breakdown voltage of the electrodes shall be lower than that of the isolating joint across which they are mounted.
- The spark gap shall be capable of discharging the expected fault and/or lightning currents without sustaining damage.
- The spark gaps shall be fully encapsulated to prevent sparks in open atmosphere and to protect the spark gaps from moisture ingress.
- The cable length shall be adequate.

Devices other than the spark-gap type may be used if reliable and properly documented.

9.6 CP cables and cable connections

Cables shall be laid without coils or kinks and buried in fine-graded soil or sand at a depth of at least 0,5 m, or in accordance with local regulations, whichever is deeper. Buried cables should be of one continuous length

without splices and should not be laid in the vicinity of power cables. Impressed-current anode cables should be connected to the positive feeder cable inside an above-ground distribution box to enable current monitoring. Alternatively, connections between the positive cable to the transformer-rectifier and the individual anode cables may be made below ground using fully encapsulated line taps.

Cable routes should be marked using cable markers installed at approximately 100 m intervals and at every change of direction.

Cables should be made of copper and shall be insulated and sheathed to withstand the prevailing chemical and mechanical (soil) conditions. Cables shall be sized such that no excessive voltage drops occur which reduce the capacity of the system. The minimum conductor size for measurement cables should be 4 mm². For multiple connections, the single cross-section of each conductor should be 2,5 mm².

The minimum conductor size for cables that carry impressed current should be 16 mm². For cables to galvanic anodes, the minimum cross-section should be 4 mm².

The cables of galvanic anodes should be connected to the pipeline in an above-ground distribution box to allow current monitoring and disconnection of each individual anode.

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 suitable coating material.

A detailed cable-to-pipeline connection procedure shall be included in the CP design. Welders and welding procedures shall be qualified for any applicable welding process in accordance with ISO 13847. Welding of cable connections shall not be carried out on bends or within 200 mm from pipeline welds. Below-ground electrical connections shall be encapsulated or coated using a material which is compatible with the pipeline coating.

Where thermite 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 pipe specification.

Thermite weld charges should not be greater than 15 g. If cables of cross-section larger than 16 mm² need to be attached, the cores shall be separated into a number of smaller strands, each less than 16 mm², and welded separately.

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

For thermite welding on live pipelines, a safety procedure shall first be developed, addressing the following:

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

Alternative methods such as pin-brazing, soft-soldering, adhesive-bonding or fusion-welding may be used provided that the detailed procedure and performance are reliable and properly documented.

9.7 Monitoring stations and distribution boxes

Monitoring stations and distribution boxes shall provide sufficient room and heat dissipation for the termination of test cables and for the installation of bonding cables and resistors as required. The need for additional space to accommodate temporary data-loggers, timers and other test facilities shall be considered.

Monitoring stations and distribution boxes should be provided with lockable access doors or caps, as applicable.

Distribution boxes should be installed above ground and there should be access to all internal components.

Monitoring stations and distribution boxes shall be weatherproofed to withstand the worst environmental conditions.

Monitoring stations and distribution boxes shall be accessible during all seasons and shall be designed and located to minimize vandalism or accidental damage.

Distribution boxes and monitoring stations used for bonding of current-carrying cables should be located outside hazardous areas or, if this is not possible, shall be approved for the relevant electrical area classification.

10 Commissioning

10.1 General

Commissioning involves the testing of all CP equipment, accessories and systems to ensure that the pipeline is protected in accordance with the design parameters.

10.2 Equipment tests

Prior to energizing the CP system, the following equipment should be tested:

- a) transformer-rectifiers and drainage stations:
 - measure the insulation resistance to ground (minimum shall be 10 M Ω at 30 °C);
 - measure the electrical resistance of earth connections;
 - check the tightness of screws and nuts;
 - check that accessories are securely mounted;
 - check the correct functioning of the unidirectional device (diode);
 - check the full-range current output that can be obtained;
 - check the correct polarity of pipeline and groundbed cables.
- b) oil-cooled transformer-rectifiers; additionally check the following:
 - oil level;
 - dielectric strength of the oil.
- c) effectiveness of the isolating joints, electrical isolation of earthing devices and metallic casings;
- d) resistance-to-earth of the groundbed;
- e) monitoring stations:
 - check the correct marking of cables and terminals;
 - check the soundness of cable connections and the integrity of safety devices (insulation and earthing, lightning protection, relevant electrical area classification);
 - check the tightness of cable terminations.

10.3 System tests

Commissioning tests involve activities which should be carried out both before and after energizing the CP system. Annex A gives details of the measurements.

Measurements of corrosion potentials should be carried out at the monitoring stations prior to energizing the CP system. When corrosion potential measurements are carried out, all temporary CP systems shall be disconnected and the pipeline shall be fully depolarized (see Figure A.1).

After energizing the CP system, the current shall be adjusted step by step until the potential at the drain point reaches the limiting critical potential. The transformer-rectifier shall be left at this setting until the pipeline is polarized.

Immediate action shall be taken if positive changes in pipeline potential occur after energizing the transformer-rectifier. Annex C describes some typical trouble-shooting information.

Once the CP system has been energized and set at the design value, the rectifier output voltage and the current output should be recorded. The pipe-to-soil potential shall be measured to verify CP effectiveness using the protection criteria in 5.3. Measurements should be carried out on adjacent structures where there is a risk of interference. In the event that potential levels are different from those specified in the design, the setting of the CP system(s) should be adjusted accordingly.

If a.c. or d.c. interference currents are present, measurements shall be taken to determine the impact of the interference on the effectiveness of the CP. These measurements shall be carried out with the CP systems both in operation and de-energized. In both cases, the pipe-to-soil potential shall be recorded for at least 24 h. When the CP system is energized, the drainage current should also be recorded.

Methods for detection of interference current and resolving interference corrosion problems are described in Annex B.

11 Inspection and monitoring

11.1 General

Inspection and monitoring of the CP system shall be carried out at regular intervals to confirm that the protection criteria are fulfilled and to detect any deficiencies (see Annex A). A further objective can be to collect data for optimization of future CP designs.

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

- review the adequacy of the corrosion management,
- identify possible deficiencies and improvements,
- indicate the necessity for a more detailed assessment of the pipeline condition.

11.2 Frequencies of inspection

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

- type of protection;
- corrosive nature of the soil;
- susceptibility of pipeline to mechanical damage;

- a.c. or d.c. interference currents;
- susceptibility of the CP installations and coating to damage by lightning or mechanical means;
- coating quality;
- safety and environmental concerns;
- age and history of the pipeline.

Routine functional checks, e.g. pipeline-to-soil potentials, transformer-rectifier voltage and current outputs etc., shall be carried out in accordance with Table 4.

Table 4 — Routine functional checking frequencies

Item	Action	Frequency
Impressed-current station	Check that the operation and condition of the transformer-rectifier unit is satisfactory and record the output voltage and current	every one to three months depending on operational conditions such as lightning, stray currents, construction activities.
Drainage stations	Measure drain-point potential and the current	at least monthly
Connections to foreign pipelines	Measure current flow	at least annually
Bonding devices and grounding systems	Measure electrical continuity	at least annually
Safety and protection devices	Measure settings and function	at least annually
At monitoring stations	Measure instant-off potentials	annually ^a
Less frequent measurements may be considered based on results of specialized surveys (see 11.5) and the stability of the system with reference to the absence of interference from stray currents, lightning, fluctuating soil conditions, etc. For stable systems, instant-on potential at selected monitoring stations shall be measured at least annually.		
^a For stable systems, instant-off potential shall be measured at all monitoring stations every 3 years.		

Specialized surveys should be conducted within 1 year of operation. Annex D provides information on various types of specialized survey.

The type and frequencies of further specialized surveys will depend on factors such as suspected coating deterioration, effects of elevated temperatures, construction activities, interference currents, etc.

If a remote CP-monitoring system has been installed and malfunctioning of equipment can be immediately detected, functional checks may be conducted less frequently than recommended above.

Results provided by the remote monitoring system should be periodically checked against manually recorded data to ensure that the remote monitoring system is functioning correctly.

11.3 Monitoring plan

A monitoring plan for the CP 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.

11.4 Monitoring equipment

For regular monitoring of CP systems, the d.c. voltmeters shall have an accuracy of ± 5 mV in the range of 0 V to 10 V (potential measurements) and an accuracy of $\pm 0,5$ mV in the range of 0 V to 1 V (gradient measurements) and a minimum input impedance of 10 M Ω . At high soil resistivities it may be necessary to use a meter with an input impedance of 100 M Ω .

When carrying out potential measurements in coastal areas where the soil contains high amounts of chloride salts, CSE shall not be used.

Although CSE is used in most applications, other standard reference electrodes may be used. Three alternative reference electrodes are listed below, along with the respective protection potentials for carbon steels (at 25 °C) equivalent to -850 mV referred to CSE:

- a) saturated KCl calomel reference electrode, for which the protection potential is -780 mV;
- b) saturated silver/silver chloride reference electrode used in 25 Ω -cm seawater, for which the protection potential is -800 mV;
- c) zinc in a backfill consisting of 75 % gypsum, 20 % bentonite and 5 % sodium sulfate, for which the protection potential is $+ 250$ mV.

Reference electrodes shall be constructed in such a manner that their potential is not affected during voltage measurement. Reference electrodes should be periodically calibrated by checking them against laboratory-type reference electrodes.

11.5 Specialized surveys

The need for, and frequency of, specialized surveys shall be based on inspection results and pipeline history (see 11.2).

A number of specialized survey techniques exist which provide additional detailed information on the status of the pipeline corrosion prevention system. These surveys are normally conducted by trained personnel using purpose-built equipment and instrumentation. Such surveys are recommended when excessive coating damage is suspected and/or localized areas of inadequate CP are observed.

12 Maintenance and repair

Effectiveness of the CP 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. These actions can include one or more of the following:

- maintain, repair or replace components of the CP system;
- provide additional facilities (rectifiers, groundbeds, galvanic anodes, etc) where protection is inadequate;
- repair identified coating defects;
- repair or replace interference bonds;

- remove unintended metallic contacts;
- repair defective isolating devices.

Potentials that do not meet the criteria stated in Clause 5 shall be investigated and all deficiencies corrected as soon as practical, but at least prior to the next survey. Inoperative rectifiers shall be repaired and returned to service as soon as possible, typically within 30 days. Significant positive shifts in pipeline potential, such as those due to stray-current interaction, shall be corrected within 30 days (Annex B).

Transformer-rectifier units and current drainage stations shall be visually checked for serviceability and damage at least annually (see 11.2).

Performance of the CP monitoring equipment, e.g. voltmeters, reference electrodes, shall be regularly verified by functional checks. This equipment also requires routine calibration and periodic safety checks.

Groundbeds can suffer from drying out at certain times of the year, evidenced by an increase in the groundbed electrical resistance. This will normally require the transformer-rectifier output voltage to be increased at these times to satisfy the current demand. Addition of water to the groundbed may help to reduce the groundbed resistance to previous levels.

Isolating devices sited above ground and open to the weather should be inspected periodically and cleared of any accumulated debris, which can bridge the insulation material. Any protective barrier coating applied to prevent the ingress of dirt, or the 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.

13 Documentation

13.1 Design documentation

13.1.1 General

The basic design documentation shall include

- results of any site surveys and soil investigations that have been carried out,
- results of any current drainage tests that have been carried out for the retrofitting of CP on existing pipelines,
- any requirements for modifications with respect to existing pipeline systems such as minimum electrical separation or coating repairs,
- calculations of current requirements, potential attenuation, electrical resistance and current output of groundbeds,
- description of system including a schematic diagram of the proposed CP system,
- a list of the estimated number and types of CP monitoring facilities,
- any sensitivities in the CP system that require special attention,
- a schedule of materials,

- a set of design drawings, and
- a set of installation procedures.

13.1.2 Construction details and installation procedures

Full construction details and installation procedures of the CP system should be documented to ensure that the system will be installed in accordance with this part of ISO 15589.

These should include

- 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,
- construction drawings including but not limited to plot plans, locations of CP systems and test facilities, cable routing, single-line schematics, wiring diagrams and groundbed construction and civil works, and
- procedures to ensure safe systems of work during the installation and operation of the CP system.

13.2 Commissioning documentation

After the successful commissioning of the CP 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 CP of the pipeline;
- as-built drawings, reports and other details pertaining to the CP of the pipeline;
- records of the interference tests (if any) carried out on neighbouring structures;
- the voltage and current at which each CP system was initially set and the voltage and current levels to be used during future interference tests. The location and type of interference-current sources (if any);
- records of the pipe-to-soil potentials at all monitoring stations before and after the application of CP.

13.3 Inspection and monitoring documentation

The results of all inspection and monitoring checks shall be recorded and evaluated. They shall be retained for use as a baseline for future verifications of CP effectiveness.

13.4 Operating and maintenance documentation

An operating and maintenance manual shall be prepared to ensure that the CP system is well documented and that operating and maintenance procedures are available for operators. This document shall consist of

- a description of the system and system components,
- the commissioning report,
- as-built drawings,
- manufacturer's documentation,
- a schedule of all monitoring facilities,

- potential criteria for the system,
- monitoring plan,
- monitoring schedules and requirements for monitoring equipment,
- monitoring procedures for each of the types of monitoring facilities installed on the pipeline, and
- guidelines for the safe operation of the CP system.

13.5 Maintenance records

For maintenance of the CP facilities, 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;
- drainage stations, casing and remote monitoring equipment.

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Annex A (normative)

CP measurements

A.1 General

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

- rectifier output voltage and current;
- on- and, if practical, instant-off pipe-to-soil potentials;
- on-potentials on bonded foreign pipelines and the magnitude of the current flow to or from them;
- magnitude of any d.c. interference with a foreign pipeline;
- magnitude of any a.c. or d.c. interference current from a foreign source;
- potential at and current flow from coupons or probes;
- effectiveness of any electrical isolation.

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 shall be assessed by potential measurement, i.e. measurements of actual potential at the pipe-to-soil 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 soil resistivity and the presence of interference currents, equalizing currents, telluric currents, etc.

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

NOTE 2 Where the only currents flowing in the soil 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-soil interface.

A.2.2 On-potential measurement

On-potential measurements are taken while the CP system is continuously operating.

To minimize the IR drop, the reference electrode should be placed as close to the pipe as possible.

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

A.2.3 Instant-off potential measurement

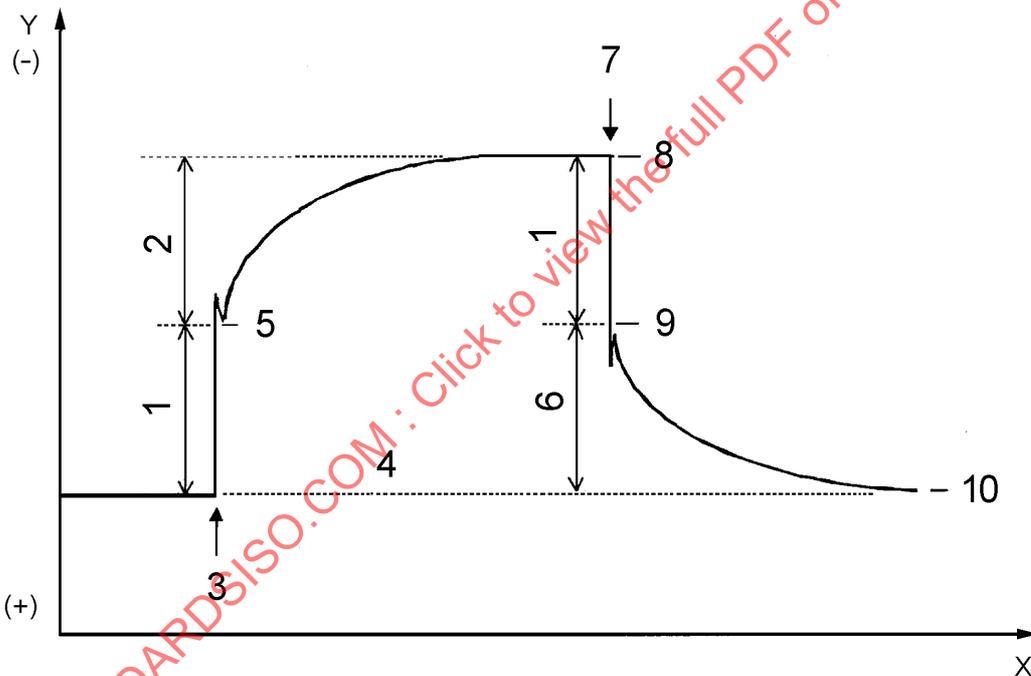
By using the instant-off potential technique, the IR drop caused by the protective current can be eliminated. The values obtained are referred to as instant-off potentials. For buried pipelines, the potential measured against the reference electrode shall be measured, generally within 1 s after the protective current is switched off. If rapid depolarization occurs, the instant-off potential shall be determined using a high speed data logging processor.

The instant-off potential shall be measured by a rapid response instrument. The ratio of the on- to off-periods shall be chosen to avoid significant depolarization.

For an effective instant-off potential measurement, all sources of CP current to the pipeline shall be switched off simultaneously. Figure A.1 shows a typical potential profile during an on-potential or off-potential measurement and how the IR drop component of the potential measurement, caused by the CP current flowing in the soil, can be removed to give the more accurate polarized potential.

NOTE Other direct current sources, equalizing currents, telluric currents and interference currents can influence the measurement and therefore give results which are not the true polarized potential.

Alternative off-potential measurement techniques may be considered if shown to be accurate and effective.



- | | |
|--|--|
| Key | 6 depolarization |
| 1 IR Drop | 7 rectifier off |
| 2 polarization | 8 on potential |
| 3 rectifier on | 9 instant-off potential |
| 4 corrosion potential | 10 depolarized potential (corrosion potential) |
| 5 instant-on potential | |
| X Time | |
| Y Structure-to-electrolyte potential, mV | |

Figure A.1 — CP polarization diagram

A.2.4 Coupon measurement

An assessment of the IR-free potential of the pipeline at a specific location can also be made from instant-off potential measurements on test coupons located adjacent to and at the same depth as the pipeline. Instant-off potential measurements should be taken immediately after the coupon is disconnected from the pipe and without interrupting the sources of protective current.

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. Coupons are connected to the pipeline by an accessible test link, which can be temporarily disconnected.

NOTE 1 It can be assumed that the coupon metal will adopt a potential, with respect to the adjacent soil that is similar to the pipe-to-soil potential at a coating defect with the same size on the pipe.

NOTE 2 Despite there being no current flowing to the coupon directly when it is disconnected from the pipe, current will still be flowing in the soil surrounding pipe and coupon. Thus, with the reference electrode located at the ground surface there can still be a significant contribution to the measured coupon potential from the IR drop in the soil. Coupon instant-off potentials are more accurate if measured against a permanent reference electrode buried alongside the coupon or permanently built in as a facility (polarization probe). The residual IR drop can also be minimized by placing the portable reference electrode in a soil tube which has one end that is positioned near the coupon and is extended to the surface.

A.3 Control of electrical isolation

A.3.1 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 system;
- degradation or lack of internal coating where the pipeline is carrying an electrically-conductive fluid.

There are a number of measurements that can be carried out to determine the effectiveness of an installed isolating joint or isolating flange kit, as described in A.3.2 through A.3.5. Where some doubt exists, a combination of two or more of the methods described can provide more certainty.

A.3.2 Pipe-to-soil potential measurements

Pipeline-to-soil 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 can not be readily identified as being defective, since the potential on both sides of the joint may still be different. As a general guide a potential difference of less than 100 mV may be regarded as inconclusive.

A.3.3 Electrical resistance measurements

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

NOTE 1 d.c. resistance meters give false indications due to polarization effects.

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 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 using an ohm-meter or other similar device.

A.3.4 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), the isolating device may be considered to be effective.
- 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 partly defective isolating device may not be readily identifiable by this method, since the current in the bond may not be zero if the leakage resistance and the bond resistance have similar magnitudes.

A.3.5 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.

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Annex B (normative)

Electrical interference

B.1 General

Corrosion caused by interference current on buried metallic pipelines differs from other causes of corrosion damage, in that the current which causes the corrosion has a source foreign to the affected pipeline. Usually, the interfering current from a foreign source, not electrically continuous with the affected pipeline, is drained from the soil by the affected pipeline. Detrimental effects of interference currents occur at locations where the currents are subsequently discharged from the affected pipeline to the earth.

Types of d.c. interference are

- constant current sources, such as from CP rectifiers, and
- fluctuating current sources, such as d.c.-electrified railway systems and transit systems, coal mine haulage systems and pumps, welding machines and direct current power systems.

Types of a.c. interference are

- 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, and
- telluric currents.

B.2 d.c. interference

B.2.1 Measurements

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

- measure pipe-to-soil potentials with recording or indicating instruments;
- measure current density on coupons;
- measure current flowing on the pipeline with recording or indicating instruments;
- measure variations in current output of the suspected source of interference current and correlate them with measurements obtained as above.

The measurements should be carried out for a period of at least 24 h, or a period which is typical for the suspected interference phenomenon being investigated, to assess the time dependence of the interference level.

Interference with other buried pipelines or installations shall be measured while the CP system is energized. Interference measurements shall be conducted as follows:

- measure both the foreign pipeline and the interfering pipeline pipe-to-soil potential while the relevant sources of CP current that can cause interference are simultaneously interrupted;
- measure the pipe-to-soil potential at the other pipeline or installation while the CP system is energized.

The mean change of potential at any part of another pipeline or installation from interference should not cause potentials outside the criteria given in 5.3. In the event of interference resulting in the CP criteria not being met, remedial action shall be taken to eliminate the interference.

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

Common methods to be considered in resolving interference problems on pipelines or other buried structures include

- prevention of pick-up or limitation of flow of interfering current through a buried pipeline,
- a metallic conductor connected to the return (negative) side of the interfering current source,
- counteraction of the interfering current effect by means of increasing the level of CP, and
- removal or relocation of the interfering current source.

Further guidance on methods for mitigating d.c interference corrosion is given in prEN 50162.

Specific methods to be considered, individually or in combination, are as follows:

- design and installation of metallic bonds with 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 uni-directional control devices, such as diodes or reverse current switches;
- coating the bare pipe where interference current enters the pipeline;
- application of additional CP current to the affected pipeline at those specific locations where the interfering current is being discharged;
- adjustment of the current output from mutually interfering CP rectifiers;
- reduction or elimination of the pick-up of interference current by relocation of the groundbeds;
- installing properly located isolating joints in the affected pipeline. Testing at the isolating joint should be done to assure that an interference condition has not then been introduced;

NOTE While installing isolating joints will reduce the magnitude of the stray current, it also introduces another current pick-up and discharge location, hence the reason for testing at the isolating joint.

- improvement in the protective coating on the interfering structure;
- installation of isolating shields between the pipeline and the interfering structure.