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Petroleum and natural gas industries — Cathodic protection for pipeline transportation systems —

Part 1:
On-land pipelines

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

Partie 1: Conduites terrestres

ICS 75.200

ISO/CEN PARALLEL ENQUIRY

The CEN Secretary-General has advised the ISO Secretary-General that this ISO/DIS covers a subject of interest to European standardization. **In accordance with subclause 5.1 of the Vienna Agreement, consultation on this ISO/DIS has the same effect for CEN members as would a CEN enquiry on a draft European Standard.** Should this draft be accepted, a final draft, established on the basis of comments received, will be submitted to a parallel two-month FDIS vote in ISO and formal vote in CEN.

To expedite distribution, this document is circulated as received from the committee secretariat. ISO Central Secretariat work of editing and text composition will be undertaken at publication stage.

Pour accélérer la distribution, le présent document est distribué tel qu'il est parvenu du secrétariat du comité. Le travail de rédaction et de composition de texte sera effectué au Secrétariat central de l'ISO au stade de publication.

In accordance with the provisions of Council Resolution 15/1993 this document is circulated in the English language only.

Conformément aux dispositions de la Résolution du Conseil 15/1993, ce document est distribué en version anglaise seulement.

Contents

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 3.

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 part of ISO 15589 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 15589-1 was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum 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 for pipeline transportation systems*:

Part 1: On land pipelines

Part 2: Offshore pipelines

Annexes A and B form a normative part of this International Standard. Annex C and D are for information only.

Introduction

Pipeline cathodic protection comprises the supply of sufficient direct current to the external surface of a metal pipe, such that the steel to electrolyte potential is lowered to values where external corrosion becomes insignificant.

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 International Standard should be aware that further or differing requirements may be needed for individual applications. This International Standard 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 International Standard should be identified.

Petroleum and natural gas industries — Cathodic protection for 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 for the petroleum and natural gas industries as defined in ISO 13623.

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

This part of ISO 15589 may be applied to retrofits, modifications and repairs made to existing pipeline systems.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

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 – Field and shop welding of pipelines*

IEC 60529 *Degree of protection provided by enclosures*

IEC 60529-14 - *Electrical installations in hazardous areas*

ASTM C 97 – 89 [1]*– 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, Conshohoeken, PA 19428-2959, USA

3 Terms and definitions

For the purpose of this International Standard the 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 of the anode to the electrolyte

3.2
bond
metal conductor, usually of copper, connecting two points on the same or on different structures usually with the intention of making the points equipotential

3.3
coupon
representative metal sample of known surface area used to quantify the extent of corrosion or the effectiveness of applied cathodic protection

3.4
current density
amount of current per unit area of the bare steel surface in contact with the electrolyte

3.5
drain point
location of the negative cable connection to the protected structure through which the protective current returns to its source

3.6
IR drop
voltage, due to any current, developed in an electrolyte such as the soil, between the reference electrode and the metal of the pipe, in accordance with Ohm's Law

3.7
isolating joint
electrically discontinuous connection between two lengths of pipe, inserted in order to provide electrical discontinuity between them, e.g. monobloc isolating joint, insulating flange, isolating coupling

3.8
natural potential
pipe to soil potential measured when no cathodic protection is applied and polarisation caused by cathodic protection is absent

3.9
On potential
pipe to soil potential measured while the cathodic protection system is continuously operating

3.10
polarised potential
IR free potential
Off potential
pipe to electrolyte potential measured without the voltage error caused by the IR drop from the protection current or any other 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 polarisation has decreased.

3.11
remote earth
that part of the electrolyte in which no noticeable voltages, caused by current flow, occur between any two points.

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

4 Symbols and abbreviations

a.c.	alternating current
d.c.	direct current
CIPS	close interval potential survey
CP	cathodic protection
ρ	resistivity (Ωm)
SCC	stress corrosion cracking

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 cathodic protection systems for on land pipelines 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;
- location, route and rating of high voltage overhead or buried power lines;
- valves and regulating station locations;

- water, railway and road crossings;
- sleeve 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 sub-stations 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 Protection potentials

The CP system shall be capable of polarising all parts of the buried pipeline to potentials more negative than –850 mV using the $Cu/CuSO_4$ (saturated) reference electrode, and to maintain such potentials throughout the design life of the pipeline. These potentials are those which exist at the metal to environment interface when the protective current is flowing, but which are normally measured by switching off the protective current momentarily (see annex A). They correspond to the polarised potential as given in Figure A.1.

NOTE IR-free potentials or Off-potentials are also terms used for measuring the polarised potential.

For carbon and low alloy steels, the polarised potential should not be more negative than –1200 mV using the $Cu/CuSO_4$ (saturated) reference electrode to avoid the detrimental effects of hydrogen production and/or a high pH at the metal surface.

For high strength (SMYS>700 MPa) steels and corrosion resistant alloys like martensitic and duplex stainless steels, the protective potential shall be assessed with respect to the detrimental effects of hydrogen formation at the metal surface where the maximum negative potential becomes more positive.

Stainless steels and other corrosion resistant alloys generally need more positive protection potentials than –850 mV using the $Cu/CuSO_4$ (saturated) reference electrode criterion. However, for most practical applications this criterion can be used.

For pipelines operating in anaerobic soils and where there are known, or suspected to be significant quantities of sulphate reducing bacteria and/or other bacteria having detrimental effects on pipeline steels, more negative potentials than –950 mV using the $Cu/CuSO_4$ (saturated) reference electrode should be necessary to control external corrosion..

For pipelines operating in soils, with very high $\rho > 100\ \Omega m$, a protective potential more positive than -850 mV using the $Cu/CuSO_4$ (saturated), e.g. –750 mV for $100\ \Omega m < \rho < 1000\ \Omega m$ and –650 mV for $\rho > 1000\ \Omega m$, may be applied, if it is demonstrated that adequate protection against external corrosion is achieved.

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

A minimum of 100mV of cathodic polarisation between the pipeline surface and stable reference electrode contacting the electrolyte may be used, if it is demonstrated that adequate protection against external corrosion is achieved. The formation or decay of polarisation should be measured to satisfy this criterion (see Figure A.1).

Other practical reference electrodes to $Cu/CuSO_4$ electrode may be used for the various criteria provided that their properties are reliable and documented.

For pipelines operating at temperatures above 40 ^{0}C, the above values may not provide adequate protection potential.

5.4 Pre-design 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 can be used provided that the date, conditions and source of such surveys are documented in a survey report. If the area to be surveyed is affected by seasonal changes, these changes 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 in 5.2.

Representative soil resistivity values shall be obtained at pipeline depth along the route of the pipeline, and at various depths at prospective locations for anode ground beds. The number of measurements shall be based onlocal 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 can include chemical and bacterial analyses of the soil. This requirement shall be extended to the imported soil used for pipeline 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 describes methods for 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 also be installed 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./d.c. interference currents;
- between cathodically protected pipelines and non-protected facilities.

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

Safety or instrument earthing and the CP system shall be mutually compatible. In areas where there may be an unacceptable risk of high voltages on the pipeline exceeding the joints 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 to a length sufficient to avoid interference current corrosion. All sealing, coating and isolation materials shall be resistant to the fluid transported.

The electrical resistance across isolating joints should be more than $10^6\ \Omega$ measured at 1000 V d.c. in dry air before installation.

All monobloc isolating joints should be fitted with surge arrestors or elctrical earthing to prevent damage from overvoltages.

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

The pipeline under cathodic protection shall be electrically isolated from common or plant earthing systems to avoid a loss of current.

All parts of the pipeline system shall be isolated from supports, utility piping, electrical systems, etc.

NOTE Normally this requires a special study as the current requirements of plant grounding systems have a much higher current demand than a well coated pipeline.

5.6 Electrical earthing

If the pipeline needs to be earthed for safety, the earthing shall be compatible with the cathodic protection system. This can be achieved for

- short term interference by a spark gap installed into the connection to the earthing;
- high voltages interferences by d.c. decoupling devices installed in the earthing circuit;.
- long term a.c. interference by suitably specified and rated devices which let a.c. but not d.c. current flow.

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

NOTE Electrical earthing devices can be installed on the pipeline to mitigate the effect of induced or ohmic electrical a.c. voltages at locations determined by investigation. These electrical voltages can be a hazard to personnel. They can also cause accelerated corrosion at the point where the induced current discharges from the pipe wall directly to earth.

5.7 Electrical continuity

Under certain circumstances it can 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 test post.

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

5.8 Current requirements

For new pipelines, the total current demand, I_{tot} ,shall be determined by evaluation of the design parameters and the previous experience from similar systems using equation 5.1:

$$I_{tot} = i \cdot n \cdot 2 \cdot \pi \cdot r \cdot L \qquad (5.1)$$

where:

i is the design current density

n is the coating breakdown factor

r is the outer radius of the pipeline

L is the length of pipeline

Tables 1 and 2 give values for design current density and coating breakdown that can be used if relevant previous experience is not available.

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

Table 1 — Design current densities for bare steel in soils with different resistivities (for operating temperatures ≤ 30 °C)

Soil resistivity Ωm	Design current density A/m^2
<10	0,020
10 – 100	0,010
>100 – 1000	0,005
> 1000	0,001
For pipelines operating at elevated temperatures, the current values shall be increased by 25 % for each 10 °C rise in operating temperature above 30 °C. Alternative current values may be used if reliable and properly documented.	

Table 2 — Coating breakdown factors n for various pipeline coatings to be used in the design of CP systems

Pipeline coating	Design Life years		
	10	20	30
Asphalt/coal tar enamel	0,01	0,04	0,09
Fusion bonded epoxy	0,01	0,04	0,09
Liquid epoxy	0,03	0,1	0,3
3 layer Epoxy-polyethylene	0,001	0,004	0,009
3 layer Epoxy-polypropylene	0,001	0,004	0,009
For design life more than 30 years correspondingly greater factors should be used. NOTE It is assumed that pipeline construction and operation is carried out in such a manner that coating damage is minimised.			

The CP system can be designed in such a way 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 CP stations.

5.9 Type of CP system and selection of sites

5.9.1 General

The CP should be accomplished by installing impressed current systems as the preferred method. Alternatively the CP can be accomplished by the use of galvanic anodes. Limitations on CP systems by galvanic anodes 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;
- low resistivity soils in the area of prospective groundbeds;
- soil resistivity along the pipeline route;
- impact of the system on existing or future third party pipelines and other developments;
- good access to the installation of rectifiers and test points;
- sufficient distance between the proposed ground-bed sites and the pipeline to obtain adequate current distribution along the pipeline;
- existence of areas classified as hazardous areas along the pipeline route;
- possibility of interference current sources.

5.9.2 CP for thermally insulated pipelines

The need for and the type of CP for thermally insulated pipelines shall be subject to an additional evaluation.

NOTE 1 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.

NOTE 2 The installation of a CP system, solely to protect an insulated pipeline, will normally be 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 soil conditions.

NOTE 3 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.

NOTE 4 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 voltage pick up points, then these voltages can travel for considerable distances and be a safety hazard to personnel who make direct contact with the pipe.

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 the 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;
- a.c. content of the d.c. output (acceptable ripple factor);
- identification and rating plate details.

High voltage gradients in the soil in the vicinity of ground beds can be a hazard to animals and persons. If voltages higher than 50 V are used, investigation of consequences to safety shall be evaluated.

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 impressed current CP system can be of deepwell or shallow type and shall be designed and located such that

- mass and material quality will satisfy the design life of the CP system;
- resistance to remote earth of each groundbed allows maximum predicted current demand to be met at 80 % or less of the voltage capacity of the d.c. source during the design life of the CP system;
- harmful interference on neighbouring buried structures is avoided.

In selecting the location for and the 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);
- 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.

6.2.2 Deepwell groundbeds

Deepwell 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 ground-bed is limited;
- there is a risk of interference currents being generated on adjacent installations.

The detailed design shall include a procedure for drilling the deepwell, establishing the resistivity of the soil at various depths, completion of the borehole and the method of installation of the anodes and the 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 stabilising the borehole in the active section of the ground-bed. The metallic casing shall be electrically isolated from any structures on the surface.

NOTE Metallic casings will only provide temporary borehole stabilisation 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 mid point of the active depth should be used.

Deepwell groundbeds should be provided with adequate vent pipes to prevent gas blocking of 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 used if the soil conditions at shallow depths meet the requirements stated in 6.2.1.

Shallow groundbed anodes can be installed horizontally or vertically. In either case the highest point of the conductive backfill shall not be less than 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.

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 metal;
- platinised 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 the required anode current output meeting the design life of the CP system. A carbonaceous or other conductive backfill material should be used unless, the soil resistivity suggests a satisfactory groundbed resistance can be achieved, and the soil is homogeneous and suggests uniform consumption of the anode will occur.

6.3 Current output control and distribution

6.3.1 General

The current output should be controlled manually 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, it can be necessary to control the current returning from individual pipelines to satisfy the differing current demands. In such cases the pipelines should be isolated from each other and provided with an individual negative connection to the current source.

The current output from individual anodes should be independently adjustable. Resistors should be installed in the negative drain circuit to balance the current to each of the adjacent pipelines individually. Each negative circuit should be provided with a shunt and diode preventing mutual influence of pipelines during On-Off potential measurements (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.

The potential measuring circuit shall have a minimum input resistance of 10^8 Ω. The 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 overprotection in the event that a reference cell 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 humidity 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 localised (hot-spot) protection to supplement impressed current systems;
- where remote impressed current systems cannot be provided;
- at locations where the soil around the pipeline can freeze (permafrost);

Where CP by galvanic anodes is selected:

- 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 during the design life of the system.

Galvanic anodes shall be marked with the type of material (trade name), 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 3.

Table 3 — Typical chemical composition of zinc anodes

Element	Min %	Max %
Cu	-	0,005
Al	0,10	0,50
Fe	-	0,005
Cd	0,025-	0,07
Pb	-	0,006
Zn	Remainder	
The maximum amount of other elements shall be 0,002 % 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 Ωm.

7.3 Magnesium anodes

Magnesium anodes shall be performance tested in accordance with ASTM G 97 – 89. 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 4.

Table 4 — Typical chemical composition of magnesium anodes

Element	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 % 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 50 Ωm.

7.4 Anode backfill

Anode backfill for galvanic anodes should consist of a mixture of gypsum, bentonite clay and sodium sulphate. The specific composition of the anode backfill shall be determined by the need to minimise resistivity and maximise 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

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

Test posts 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;
- major road and embankment (dyke) crossings;
- railway and river crossings;
- bond connections to other pipelines or facilities;
- connections with coupons and grounding.

Test posts should also be installed where the pipeline runs close to other structures and at crossings with other pipelines.

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

Test posts should be installed not more than 2,5 m away from the pipeline.

At each test post two separate cables should be attached to the pipeline and terminated in the test post.

8.3 Foreign pipeline bonding facilities

At crossings with other pipelines, a bonding facility should be considered. It should consist of two separate cables attached to each individual pipeline, terminating in a test post with facilities to install direct or resistive bonds if required. The cables to each pipeline should be identifiable by colour coding or tags.

8.4 Test facilities at casings

If the casing length is more than 20 m, a test facility should be installed at both ends of the casing. Shorter casings may be provided with a test facility at one end only.

In each test facility, two test cables should be connected to the pipeline and, if a steel casing is used, two test cables should be connected to the casing. All cables shall be terminated in one test post.

8.5 Test facilities at isolating joints

At all isolating joints a cable connection shall be installed on each side of the joint. The connection should consist of two cables. All cables shall be separately terminated in a single test post with facilities to install direct or resistive bonds and surge arrestors.

The cables to each side of the isolating joint shall be identified by colour coding or tags.

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 should be provided.

At the drain point a potential monitoring station should be installed using a separate test cable connected to the pipeline for the measurement of the drain point potential. A potential 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

Where the risk of corrosion is high and the installation of the permanent CP system cannot be finalised before the pipeline is buried, 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/disconnected during and/or after commissioning of the permanent system.

The 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 mandatory, the design of the casing shall be such as 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.

To minimise 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 can be filled with a material with adequate long term corrosion protection properties.

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

For non-metallic casings, CP should be provided to the pipeline inside the casing by installing galvanic anodes along the bottom of the pipe together with a reference cell inside the casing. The galvanic anodes should be attached to the pipeline via a cable in a test post. The cable from the reference cell should be run back into the test post and terminated in a separate connection.

For concrete casings, the CP current can pass through the concrete provided it is sufficiently conductive and that 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 induction or the local earthing of electrical faults. Any such effects shall be investigated and devices for the protection of the pipeline and personnel shall be considered.

It shall be demonstrated (by calculation or otherwise), that no harmful voltages are present on the pipeline. If this cannot be demonstrated, then additional facilities shall be installed to prevent excessive voltages occurring. Such facilities may consist of dedicated pipeline earthing and/or polarisation cells or surge arrestors (see 9.5) across isolating joints and output terminals of d.c. voltage sources.

If high voltage is caused by conductive effects, special coating systems, re-routing of grounding systems, etc, shall be used to reduce any detrimental effects.

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) shall be mounted across isolating joints and output terminals of d.c. voltage sources.

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 such that:

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

Devices alternative to spark gap type can be used if reliable and properly documented.

9.6 CP cables and cable connections

Cables shall be laid without coils or kinks and buried at a depth of at least 0,5 m or in accordance with the governing electrical code in fine graded soil or sand. Buried cables should be of one continuous length without splices and should not be laid in the vicinity of power cables.

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

Cables should be copper cables, and shall be insulated and sheathed to withstand the prevailing chemical and mechanical (soil) conditions. The minimum conductor size for measurement cables shall be 5 mm^2. Cables shall be sized such that no excessive voltage drops occur which reduce the capacity of the system.

The minimum conductor size for cables that carry current shall be 16 mm^2. Impressed current anode cables should be connected to the positive feeder cable inside an above ground distribution box to enable current monitoring. The cables of galvanic anodes should be connected to the pipeline in an above ground distribution box to allow individual anode current monitoring and disconnection.

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.

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.

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.

Thermite 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 pipe specification.

Thermite weld charges should not be greater than 15 g. If cables larger than 16 mm^2 need to be attached, the cores shall be separated into a number of smaller strands each less than 16 mm^2 and welded separately.

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

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 Test posts and distribution boxes

Test posts 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 by the design. The provision for additional space to accommodate temporary data-loggers, timers and other test facilities shall be considered.

Test posts and distribution boxes should be provided with lockable access doors or caps as applicable.

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

Test posts and distribution boxes shall be weatherproofed to withstand the worst environmental conditions.

Test posts and distribution boxes shall be accessible during all seasons and designed and located to minimise vandalism or accidental damage.

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

10 Commissioning

10.1 General

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

10.1.1 Equipment tests

Prior to energising the CP system the following equipment should be tested:

a) transformer rectifiers and drainage stations:

- measurement of the insulation resistance to ground (minimum shall be 10^6 Ω at 30 °C);
- measurement of the electrical resistance of earth connections;
- tightness of screws and nuts;
- secure mounting of accessories;

- correct functioning of the uni-directional device (diode);
- full range current output that can be obtained;
- correct polarity of pipeline and groundbed cables.

b) transformer rectifiers oil cooled, additionally check:

- oil level;
- dielectric strength of the oil.

c) effectiveness of the insulating joints.

d) resistance to earth of the groundbed.

e) test posts :

- correct marking of cables and terminals;
- soundness of cable connections and integrity of safety devices (insulation and earthing, lightning protection, relevant electrical area classification);
- tightness of cable terminations.

10.2 System tests

Commissioning tests comprise activities, which need to be carried out both before and after energising the CP system. Annex A gives the measurement details.

Measurements of natural potentials should be carried out prior to energising the CP system by measuring the pipe-to-soil potential at test points. Any temporary CP system should be disconnected and the pipeline should be depolarised before measurements of natural potentials (see Figure A.1).

After energising the CP system, the current shall be adjusted step by step until the potential at the drain point reaches the design negative limit. The transformer rectifier shall be left at this setting until the pipeline is polarised.

Immediate action shall be taken if, after energising the transformer rectifier, positive changes in pipeline potential occur, particularly at drain points.

NOTE This indicates that the cable connections at the transformer rectifiers have been reversed.

The transformer rectifier shall be de-energised and further investigations carried out to establish the nature of the problem.

Once the CP station has been energised and set at the design value, the rectifier output voltage and the current output should be recorded. The pipe-to-soil On and Off potentials should be measured (see annex A) at all test points after a period of time which allows for polarisation of the pipeline. 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 station(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 stations both in operation and de-energised. In both cases the pipe-to-soil potential shall be recorded for at least 24 hours. When the CP station is energised the drainage current should also be recorded.

NOTE A typical scheme for detecting faults in the CP system is given in annex C. 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 criteria for adequate corrosion protection are fulfilled and to detect any deficiencies. A further objective can be to collect data for optimisation 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 should 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 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 at the following frequencies:

- impressed current station: at least monthly, check that the operation and condition of the transformer-rectifier unit is satisfactory and record the output voltage and current,
- drainage stations: measure the drain point potential and the current at least monthly;
- connections to foreign pipelines: measure the current flow at least annually;
- bonding devices and grounding systems: measure at least annually;
- safety and protection devices: measure at least annually;
- test stations: measure pipeline-to-soil potentials at all test points at least annually. Less frequent measurements may be considered based on results of specialised surveys (see 11.5).

Specialised surveys (see annex D) should be conducted when further investigations are required into the deficiencies in level of protection. CIPS should be conducted at intervals of 5 to 10 years.

NOTE The type and frequencies of specialised 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, manual potential and current measurements 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 operated and maintained.

The monitoring plan shall include as minimum:

- 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 are to 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 10 V (potential measurements) and an accuracy of 0,5 mV in the range of 1 V (gradient measurements) and a minimum input impedance of $10^6\ \Omega$.

When carrying out potential measurements in coastal areas where the soil contains high amount of chloride salts, saturated $Cu/CuSO_4$ reference electrodes shall not be used. Other reference electrodes, e.g. Ag/AgCl electrode, may be used provided that their performance is reliable and documented. Zinc reference electrodes may only be used as permanent reference electrodes in seawater saturated soils.

Reference electrodes shall be constructed in such a manner that their potential is not affected during voltage measurement. Reference electrodes should be periodically calibrated.

11.5 Specialised surveys

The need for and frequency of specialised surveys shall be based on inspection results and pipeline history (see para 11.2 and annex D).

NOTE A number of specialised 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 localised areas of inadequate CP are observed.

12 Maintenance and repair

Effectiveness of CP system shall be maintained throughout the lifetime of a pipeline. Remedial actions shall be taken when 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 where protection is inadequate;
- repair identified coating defects;
- repair or replace interference bonds;
- remove accidental metallic contacts;
- repair defective insulating devices.

Transformer rectifier units and current drainage stations shall be visually checked for serviceability and damage at least annually.

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

NOTE Surface groundbeds can suffer from drying out at certain times of the year evidenced by a seasonal 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 restore the groundbed resistance to previous levels.

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 ground-beds;
- explanation 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 proposed CP system that require special attention;
- a schedule of materials;
- a complete set of design drawings;
- a complete set of installation procedures.

13.1.2 Construction details and installation procedures

Full construction details and installation procedures of the CP system shall be documented to ensure that the system will be installed in accordance with this International Standard.

These shall include:

- written procedures for the installation of dc voltage sources, ground-beds, cables, test facilities, cable connections to the pipeline;
- written procedures for all tests required to demonstrate that the quality of the installation meets the specification;
- all relevant construction drawings including but not limited to plot plans, locations of CP stations and test facilities, cable routing, single line schematics, wiring diagrams and groundbed construction and all civil works;
- written procedures to ensure safe working practices 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;
- the CP design with as-built drawings, reports and all 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 station 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 test locations both 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 a sufficient period so that they can be used as a baseline for future verifications of CP effectiveness.

NOTE The results of all inspection and monitoring checks should be part of the CP history database and maintained for reference purposes, so that they can be used as a baseline for future verifications of CP effectiveness.

13.4 Operating and maintenance documentation

An operating and maintenance manual shall be worked out to ensure that the CP system is well documented and that operating and maintenance procedures are available for operator. 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;
- guidelines for the safe operation of the cathodic protection system.

13.5 Maintenance records

Due to maintenance of 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 of interference bonds;
- maintenance, repair, and replacement of coating, insulating devices, test leads, and other test facilities.
- drainage stations, casing and remote monitoring equipments

Annexe A

(normative)

CP measurements

A.1 General

Following electrical measurements shall be carried out during commissioning and operation:

- rectifier output voltage and current;
- ‘on’ and instantaneous ‘off’ pipe-to-soil potentials;
- ‘on’ potentials on bonded foreign pipelines and the magnitude of the current flow to or from the same;
- 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.

If there are indications that the CP is not fully effective along the entire pipeline, further investigations shall be carried out and appropriate corrective action taken to achieve the required distribution of protection.

NOTE A typical scheme for detecting faults in the 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.

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. Thus, the potential measurement with the reference electrode at the ground surface will include a contribution from the potential drop in the soil. There are complementary techniques, which can be used to give a more accurate assessment of the effectiveness of the CP. The chosen technique should be selected on basis of the local conditions in the field, e.g. the coating type and quality, the soil resistivity and the presence of interference currents, equalising currents, telluric currents, etc.

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

Potential measurements shall be taken while the cathodic protection system is continuously operating.

NOTE The values obtained contain various unknown IR drops which change with the time and position of the measurement.

To minimise the IR drop the reference electrode should be placed as close to the pipe as possible. The readings may not therefore reflect the potential at the pipe to soil interface.

A.2.3 Instantaneous-off-potential measurement

By using instantaneous-off-potential technique the IR drop caused by the protective current can be eliminated. The values obtained are referred to as ”off-potentials“. For steel/soil systems, the potential measured against the reference electrode shall be measured within one second after the protective current is switched off.

NOTE The values measured is usually representative of the polarised potential.

The off-potential shall be measured by a rapid response(<milli-Sec) instrument. The ratio of the ”on“ to ”off“ periods shall be chosen to avoid significant depolarisation.

For an effective off-potential measurement, all sources of CP current to the pipeline shall be switchedoff simultaneously. Figure A.1 shows a typical potential profile during an on/off potential measurement and how the IR drop component caused by the CP current of the potential measurement can be removed to give a more accurate polarised potential. It should be recognised that other direct current sources and interference currents will influence the measurement and therefore give results which are not the true polarised potential.

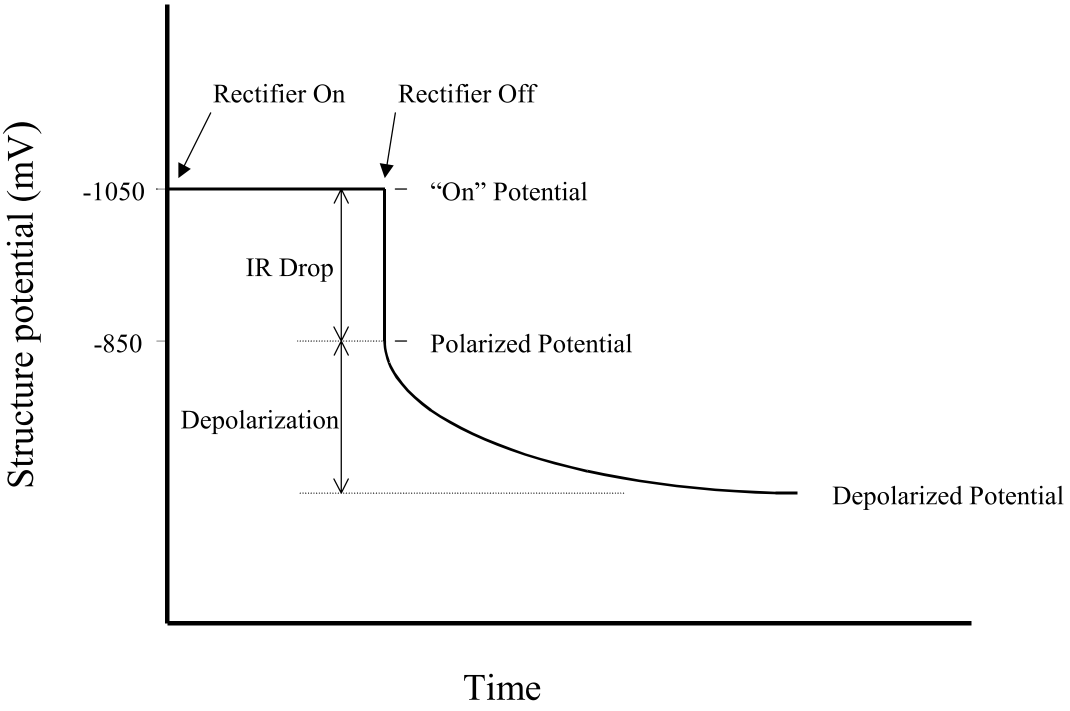

Figure A.1 — CP depolarisation diagram

A.2.4 Coupon measurement

An assessment of the IR free potential of the pipeline at a specific location can also be made from instantaneous-off-potential measurements on test coupons located adjacent to and at the same depth as the pipeline.

Coupons shall be manufactured from a material similar to the pipeline under test and have a similar coating, except for a defined area on each that is left bare. Coupons are connected to the pipeline by an accessible test link, which can be temporarily disconnected.

NOTE 1 It may 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 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 may still be a significant contribution to the measured coupon potential from the IR drop in the soil. Coupon off-potentials are more accurate if measured against a permanent reference electrode buried alongside the coupon or permanently built in as a facility (polarisation probe).

A.3 Control of electrical isolation

A.3.1 Isolation tests

A.3.1.1 General

Failures of isolating joints to perform satisfactorily may be due to one of the following ;

- defective isolating joint itself or defective insulating 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 of internal coating where the pipeline is carrying an electrically conductive fluid.

There are a number of measurements that may be carried out to determine the effectiveness of an installed isolating joint or insulating flange kit, as described in A.3.1.2 through A.3.1.5. Where some doubt exists, a combination of two or more of the methods described may provide more certainty.

A.3.1.2 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/insulating flange is effective. A partially defective insulating device may 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.3.1.3 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 polarisation effects.

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

Where an insulating flange kit has been installed, the satisfactory insulation of each bolt should be checked using an ohm-meter or other similar device.

A.3.1.4 Impressed current tests

Using impressed current tests to verify the integrity of an insulating device the following methods shall be used:

Method 1: Current shall be applied to the pipeline on one side of the insulating device. If the potential on the other side of the insulating device does not change, or changes the potential value to the opposite metering direction (due to an interference effect), the insulating device may be considered to be effective.

Method 2: The current through a temporary bond across the insulating device shall be measured when CP is applied to one side only. If there is no current flow through the bond, then the insulating device should be considered defective or being by-passed. A partly defective insulating 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.3.1.5 Audio frequency generator measurements

Audio frequency generator measurements shall be carried out by introducing a suitable audio frequency from a proprietary 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 insulating device.

A.3.2 Maintenance

Insulating 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 insulating devices are not unintentionally electrically by-passed after installation.

Whenever the effectiveness of an insulating device is tested on site, the integrity of any accompanying high voltage protection device shall also be checked in accordance with the manufacturers instructions. Test stations and test wires attached at isolating devices shall be regularly maintained.

Annexe B
(normative)

Electrical Interference

B.1 General

Regarding detection and control of a.c. and d.c. interference currents in the pipeline, the practices covered in this annex shall be used..

Corrosion caused by interference current on buried metallic pipelines differ from other causes of corrosion damage in that the direct current which causes the corrosion, has a source foreign to the affected pipeline. Usually the interfering current is collected from the soil by the affected pipeline from a direct current source not metallically bonded to the affected pipeline.

Detrimental effects of interference currents occur at locations where the currents are discharged from the affected pipeline to the ground.

Types of d.c. interference current sources are:

- constant current; these sources, such as CP rectifiers, have essentially constant direct current output;
- fluctuating current; these sources have fluctuating direct current output, such as direct current electrified railway systems, coal mine haulage systems and pumps, welding machines, direct current power systems and telluric currents;

Types of a.c. interference currents are:

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

B.2 d.c. interference

B.2.1 Measurements

In areas where d.c. interference currents are suspected, appropriated tests shall be conducted. Any one or any combination of the following test methods shall be employed ;

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

The measurements should be carried out for a period of at least 2 weeks 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 after the CP system is energised. These interference test shall be conducted according to the following procedure:

- 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 at the other pipeline or installation the pipeline-to-soil potential while the CP stations are energised.

The mean change of potential at any part of an other pipeline or installation from interference should not cause any out of protection limit condition. In case of interference resulting in the CP criteria not being met, remedial action shall be taken to eliminate the interference.

B.2.2 General methods for resolving d.c. interference corrosion problems

The following general methods should be considered to resolve interference problems on pipelines or other buried structures;

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

B.2.3 Specific methods for resolving interference corrosion problems

The following methods should be used individually or in combination.

- 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 a affected pipeline to the interfering pipeline and/or current source;
- uni-directional control devices, such as diodes or reverse currents switches;
- coating the bare pipe where interference current enters the pipeline or installing local galvanic anodes on the coated pipe;
- application of cathodic protection current to the affected pipeline at those locations where the interfering current is being discharged;
- adjustment of the current output from mutually interfering cathodic protection rectifiers can resolve interference problems;
- reduction or elimination of the pick-up of interference current by relocation of the ground-beds;
- properly located insulating joints in the affected pipeline can reduce or resolve interference problems;

B.3 a.c. interference

B.3.1 General

Permanent induction on the pipeline from high voltage a.c. sources can result in a.c.-interference which mainly depends on:

- length of parallel routing with a.c. lines;
- distance to rails or high voltage lines;
- voltage level of the pipeline;
- power load of the a.c. line;
- pipeline coating quality.

a.c.interference effects on buried pipelines can cause a number of safety issues if not mitigated effectively.

NOTE Possible effects associated with a.c. interference to pipeline include ; personnel subject to electric shocks, accelerated corrosion, damage to the coating, damage to insulators and possibly perforation of the pipeline itself.

The following types of a.c. interference on pipelines shall be considered;

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

B.3.2 Calculation of permanent a.c. induction

The a.c. interference scenario should be simulated on a computer taking into consideration each item of characterising data from the affected pipeline such as coating resistance, diameter, route, locations of isolating joints or insulating flanges. If the isolating device is bonded, the resistance to earth of the grid behind must be estimated or the grid itself shall be part of the study if also influenced by a.c. induction.

Other data to be considered are the interfering high voltage a.c. traction system, such as voltage, operating current, scheme of high voltage tower and position of the wires, route including the position of the transformers, frequency, for high power lines and electrical characteristic of the line.

B.3.3 Effects of a.c. interference currents

To determine the a.c. corrosion risk, coupons should be installed where the a.c. current density reaches its maximum. They should be buried at the pipeline depth and be easily removable for periodic visual inspection.

A maximum step and touch voltage shall be limited to safety limits and maintained at all location where a person could touch the pipeline or a pipeline component. Different voltage levels may be accepted where trained personnel or other technical factors are involved.

The a.c. current density within a coating defect is the determining factor to assess the a.c. corrosion risk. In case of low soil resistivity, high a.c. current densities can be observed.

NOTE There is a high probability of having a corrosion risk caused by AC, if the a.c. current density referred to a 100 mm² bare surface (e.g. an external test probe) is higher than 30 A/m². In certain conditions, a.c. corrosion may develop with an a.c. current density lower than 30 A/m² referred to a 100 mm² bare surface. This is mainly related to the level of a.c. current density compared to the level of d.c. current density.

B.3.4 Limiting a.c. interferences

Protection measures against a.c. corrosion should be achieved through the following measures:

- reduce the interfering a.c. voltage;
- change the d.c. level so that the positive part of a.c. current can be neglected .

To reduce a.c. voltage, the following methods should be used:

- install pipe line earthing equipped with suitable devices in order to let a.c. current flowing but not d.c. currents. A simulation on a computer may be required to optimise the number, location and resistance to earth of such earthing systems;
- install an insulating joint into the interfered pipeline in order to interrupt the longitudinal conductivity and thus limiting the length of an interfered pipeline section. The CP system shall be modified accordingly. The site of installation should be designed carefully as the level of induced a.c. voltage may be significantly changed. The variation of the profile of the induced voltage should be evaluated by a simulation on a computer;
- install active earthing potential controlled amplifiers used to impress a current into the pipeline compensating or reducing the induced voltage. This method may be applied if the required reduction of induced voltage cannot be achieved by simple earthing. The location of compensation devices shall be carefully designed.
- Mitigation of a.c. interference effects may require the addition of earthing systems to provide potential equalising at a local area. These earthing systems may be constructed using a wide variety of electrodes (galvanised steel, zinc, magnesium, etc) and some earthing systems may have an adverse effect on the effectiveness of the CP. To avoid adverse effects on the CP the earthing systems should be connected to the pipeline via appropriate devices, (e.g. spark gaps, d.c. decoupling devices, etc).

The result of shifting the d.c. voltage level to reach more negative potential is a smaller share of positive charge of the alternating current flowing within a coating defect that may reduce the a.c. corrosion rate. The d.c. level should not be so high that it engender the risk to have detrimental effects due to hydrogen development (see 5.3).

Annexe 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 tabulated below.

Observation	Indications
(a) Pipe/soil potential becomes more positive as protection system is switched on	(1) This indicates reversed connections at the transformer rectifier. A ery serious fault that could result in severe damage to the pipeline in a relative short period of time.
(b) Applied voltage is zero or very low, current is zero	(1) failure of a.c. fuse or tripping of other protective device (2) failure of a.c. supply (3) failure of transformer-rectifier
(c) Applied voltage normal, current is low but not zero	(1) deterioration of anodes or ground-bed (2) drying out of soil around ground-bed (3) accumulation of electrolytically produced gas around the anodes (gas blocking) (4) disconnection of individual anodes in a ground-bed or anode system (5) disconnection of part of the protected pipeline from the negative side of the transformer rectifier
(d) 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 ground-bed or anode system
(e) Applied voltage and current zero	(1) control on transformer-rectifier unit set too low (2) transformer or rectifier fault (3) electricity supply fault
(f) Applied voltage and current both high	control on transformer-rectifier set too high
(g) Applied voltage and current normal but pipe/soil potential insufficiently negative,i.e. too positive	(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 soil 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 station 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.
(h) Applied voltage and current normal but the pipe/soil potential abnormally negative	(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 station; (3) effects of interference current on the pipeline
(i) Applied voltage and current normal but pipe/soil potential fluctuates	presence of interference earth currents e.g. interference from d.c. traction systems or telluric/geomagnetic effects

Annexe D
(informative)

Description of specialist surveys

D.1 Pearson survey

Pearson 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 potential difference between two contacts with the soil approximately 6 m apart is measured. Two operators walk along the route, making the necessary contacts with the soil, usually via cleated boots. They walk either in-line directly over the pipeline or side-by-side with one operator over the pipeline. An increase in the recorded potential difference can indicate a coating defect or a metallic object in close proximity of the pipe.

The in-line method is helpful in the initial location of possible coating defects, since any increase in potential difference (usually determined by an increase in an audio signal) is obtained as each operator passes over the defect. However, when there is a series of defects close together, and specific information on a particular defect is required, the side-by-side method is preferred. Interpretation of the results obtained is entirely dependent on the operator unless recording techniques are used.

D.2 Current attenuation survey

Current attenuation surveys can be used to locate zones of defects in protective coatings of 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 will produce 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 will attenuate at a constant rate, which depends upon coating properties. Any significant change in the current attenuation rate may indicate a coating defect or contact with another pipeline.

D.3 Close interval potential survey - CIPS

CIPS can be used to determine the level of CP along the length of the pipeline. It can also indicate areas affected by interference and coating defects. The pipe/soil 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 point. Potential measurements against distance are plotted from which features can be identified by changes in potential caused by local variations in CP current density. The survey may be carried out with the CP system energised continuously (an ‘on-potential’ survey) or with all transformer rectifiers switching off and on simultaneously with the aid of synchronised timers.

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

D.4 Direct current voltage gradient survey - DCVG

DCVG survey can be used to locate and size defects in protective coatings on buried pipelines. By applying a direct current to the pipeline in the same manner as CP, a voltage gradient is established in the soil due to the passage of current to the bare steel at coating defects. Generally, the larger the defect, the greater the current flow and voltage gradient.

A current interrupter should be installed at the nearest transformer rectifier or a temporary current source to achieve a significant potential change (≈ 500 mV) at the pipeline.

Using a sensitive mV-meter, the potential difference is measured between two reference electrodes (probes) placed at the surface level in the soil within the voltage gradient. Defects can be located by zero readings corresponding with the probes being symmetrical either side of the defect. In carrying out the survey, the operator walks the pipeline route taking measurements at typically 2 m intervals with the probes one in front the other, 1 m to 2 m apart. The probes are normally held parallel to and directly above the pipeline, enabling the direction of current flow to the defect to be determined.

D.5 Intensive measurement technique

The combination of CIPS and DCVG is described as intensive measurement technique. It can verify the effectiveness of CP by calculating the IR free potential (E_{IRfree}) at the pipe to soil interface in the absence of interference currents. Typical positioning of electrodes are shown in Figure D.1.

The calculation of the IR free potential (E_{IRfree}) is performed by equation D.1.

$$E_{IRfree} = E_{off} - \frac{\Delta E_{off}}{\Delta E_{on} - \Delta E_{off}} \cdot (E_{on} - E_{off}) \tag{D.1}$$

where

E_{IRfree} is the calculated polarised potential (see 3.10)

E_{on} is the measured on-poential (see 3.9)

E_{off} is the measured off-potential at location (see 3.10)

ΔE_{on} is the difference between measured on-potential and a reference point, e.g. at test post

ΔE_{off} is the difference between measured off-potential and at a reference point, e.g. at test post

Using this method coating holidays are detected where ΔE_{on} - ΔE_{off} peaks are measured along the pipeline route. The absolute value of ΔE_{on} - ΔE_{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 distances of 5 m.

For ΔE_{on} > approx. 20mV, the measured values obtained generally are accurate enough to calculate the IR drop in the soil between locations (1) and (2) in figure D.1.

In the presence of equalising currents the potential gradients will be approximately symmetrical to the pipeline. Therefore it will be sufficient to determine the potential difference between the reference electrodes at locations (2) and (3) or (2) and (3') for determining the ΔE values.

In the presence of currents from remote foreign sources the potential gradients will be no longer symmetrical. The potential gradients caused by coating defects will then be the mean values of the potentials between the reference electrodes at locations (2) and (3) and at locations (2) and (3'), arranged symmetrically with the distance 'a' in figure being the same on both sides. In this case equation D.2 can be used for determining the IR free potential.

$$\Delta E = \frac{1}{2} \cdot (\Delta E_{3/2} - \Delta E_{3'/2}) \qquad \text{(D.2)}$$

For currents fluctuating with time the E and ΔE readings shall be taken simultaneously, both for the "on" and the "off" period.

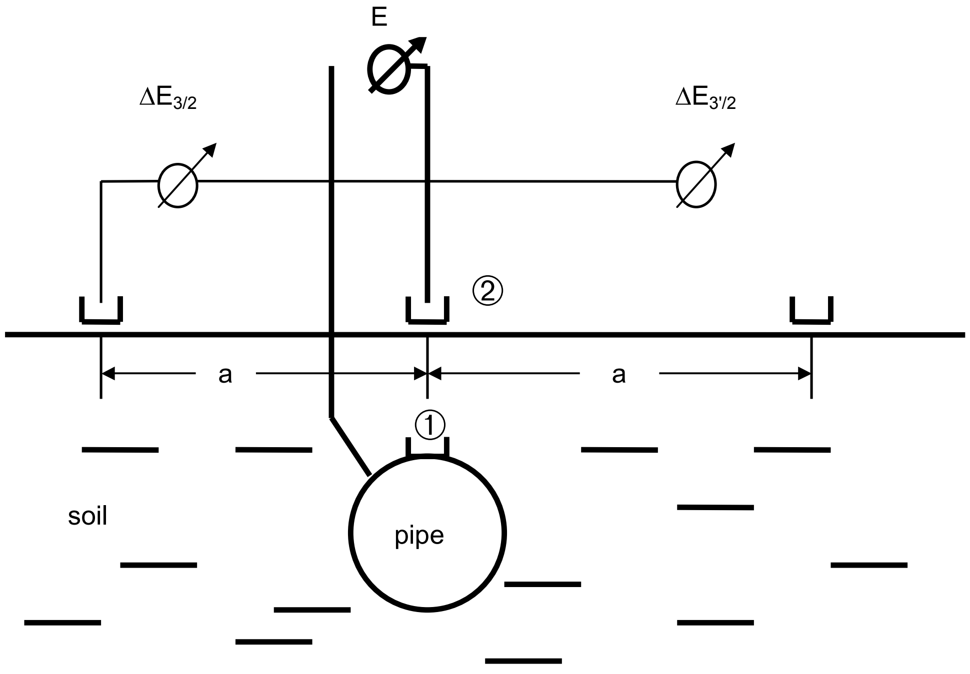

Figure D.1 : Locations (1), (2), (3) and (3') of reference electrodes for measurement of structure to electrolyte potentials and potential gradients on, for example, a buried pipeline.

━━ **Arrangement for measuring on and off potentials**

── **Additional arrangement for intensive measurement technique**