BRITISH STANDARD

BS EN 12474:2001

# Cathodic protection of submarine pipelines

The European Standard EN 12474:2001 has the status of a British Standard

ICS 23.040.01

# National foreword

This British Standard is the official English language version of EN 12474:2001.

Attention is drawn to the fact that BS 7361-1:1991, *Cathodic protection — Part 1: Code of practice for land and marine applications*, provides general information on cathodic protection. Note that BS 7361-1:1991 will eventually be withdrawn when all the CEN standards relating to cathodic protection currently being prepared are published.

The UK participation in its preparation was entrusted to Technical Committee GEL/603, Cathodic protection which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

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

**Cross-references**

The British Standards which implement international or European publications referred to in this document may be found in the BSI Standards Catalogue under the section entitled "International Standards Correspondence Index", or by using the "Find" facility of the BSI Standards Electronic Catalogue.

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This British Standard, having been prepared under the direction of the Electrotechnical Sector Policy and Strategy Committee, was published under the authority of the Standards Policy and Strategy Committee on 25 October 2001

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EUROPEAN STANDARD

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# EN 12474

April 2001

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English version

## Cathodic protection of submarine pipelines

Protection cathodique des canalisations sous marines

Katodischer Korrosionsschutz für unterseeische Rohrleitungen

This European Standard was approved by CEN on 7 March 2001.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Management Centre has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

EUROPEAN COMMITTEE FOR STANDARDIZATION
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## Contents

## Foreword

This European Standard has been prepared by Technical Committee CEN/TC 219 "Cathodic Protection", the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by October 2001, and conflicting national standards shall be withdrawn at the latest by October 2001.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

## Introduction

Cathodic protection, together with a corrosion protection coating, is usually applied to protect the external surface of submarine pipelines from corrosion due to sea water or saline mud.

The corrosion protection coating is applied on the external surface of the pipeline to insulate the steel surface from the aggressive environment into which the pipeline is surrounded.

The cathodic protection ensures the protection of the areas of the pipeline which are directly exposed to the aggressive marine environment due to damage or defects in the coating.

The cathodic protection supplies sufficient direct current to the external surfaces of the pipeline to reduce the pipe to electrolyte potential to values where there is insignificant corrosion.

The general principles of cathodic protection are detailed in EN 12473.

## 1 Scope

This European Standard establishes the general criteria and recommendations for the design, installation, monitoring and commissioning of the cathodic protection systems for submarine pipelines.

This standard is applicable to all grades of carbon manganese steel and to stainless steel pipelines; it covers all types of sea water and seabed environments encountered in submerged conditions.

The cathodic protection of short lengths of submarine pipelines and their branches, which are directly connected to cathodically protected onshore pipelines, are outside of the scope of this standard (see EN 12954:2001).

The cathodic protection of risers is included in this standard only if they are insulated from the supporting structure. The cathodic protection of the risers in direct electrical contact with the supporting structure is included in EN 12495.

## 2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

EN 12473:2000, *General principles of cathodic protection in sea water.*

EN 12495, *Cathodic protection for fixed steel offshore structures.*

prEN 12496:1996, *Sacrificial anodes for cathodic protection in sea water.*

EN 12954:2001, *Cathodic protection of buried or immersed metallic structures - General principles.*

EN ISO 8044, *Corrosion of metals and alloys – Basic terms and definitions (ISO 8044:1999).*

## 3 Terms and definitions

For the purposes of this European Standard the terms and definitions in EN ISO 8044 and the following apply:

**3.1**
**weight coating**
coating usually made of steel wire reinforced concrete, applied to the pipes to provide anti-buoyancy and/or mechanical protection of the pipeline

**3.2**
**remotely operated vehicle (R.O.V.)**
unmanned submarine vehicle operated by a surface vessel and used for inspection and survey of the pipeline

**3.3**
**"J" tube**
curved tubular conduit designed and installed on a structure to support and guide one or more pipeline risers or cables

**3.4**
**riser**
vertical or near vertical portion of an offshore pipeline which connects the platform piping to the pipeline at or below the sea bed

# 4 Criteria and principles for cathodic protection design

## 4.1 Protective criteria

### 4.1.1 Protective potentials

To achieve adequate cathodic protection a submarine pipeline should have the protective potentials indicated in the following table. These potentials apply to saline mud and normal sea water compositions (salinity 32 ‰ to 38 ‰).

**Table 1 — Summary of potential versus silver/silver chloride/sea water reference electrode recommended for the cathodic protection of steel materials in sea water**

| Material | Minimum negative potential<br>volt | Maximum negative potential<br>volt |
|---|---|---|
| Iron and steel | | |
| aerobic environment | -0,80 | -1,10 |
| anaerobic environment | -0,90 | -1,10 |
| Stainless steel | | |
| Austenitic steel | | |
| - (PREN ≥ 40) | -0,30 | no limit |
| - (PREN < 40) | -0,60 (see note 1) | no limit |
| Duplex | -0,60 (see note 1) | (see note 2) |

NOTE 1 For most applications these potentials are adequate for the protection of crevices although more negative potentials may be considered.

NOTE 2 Depending on metallurgical structure these alloys may be susceptible to cracking and more negative potentials should be avoided (in accordance with 8.3.2.2 of EN 12473:2000).

### 4.1.2 Reference electrodes

The following types of reference electrodes may be used to measure the potential between the pipeline surface and sea water:

- silver-silver chloride/seawater (Ag/AgCl/sea water);

- high purity zinc (99,9 % min. of zinc with iron content not exceeding 0,0014 %)/sea water;
- anode zinc alloy/seawater;
- saturated KCl calomel ($Hg/HgCl_2/KCl$ saturated) for reference electrode calibration purposes only.

## 4.2 Corrosion protection coating

A corrosion protection coating is normally applied to a submarine pipeline in conjunction with cathodic protection to control external corrosion. The coating reduces the current required to achieve effective cathodic protection and enhances the distribution of the cathodic protection current over the pipeline surface (see table A.3).

## 4.3 Basic parameters

The following should be taken into consideration when designing a cathodic protection system:

- characteristics of the submarine pipeline to be protected, such as diameter, wall thickness, length, route, laying conditions on the sea bottom, temperature profile along its whole length, type and thickness of corrosion protection coating(s) for pipes and fittings, presence, type and thickness of thermal insulation, mechanical protection, and/or weight coating;
- existing or proposed installations (pipelines, platforms etc.) in close proximity to or crossing of the pipeline route;
- the requirement for electrical isolation from adjoining steel structures, platform, onshore pipelines etc.;
- presence of "J" tubes, risers and clamps;
- environmental conditions;
- design life of the pipeline;
- pipeline lay method;
- protection criteria;
- offshore site i.e. accessibility for repair and replacement;
- performance data of cathodic protection systems in the same environment site;
- availability of electric power;
- safety requirements;
- applicable codes;
- risk assessment.

## 4.4 Environmental parameters

The following environmental parameters should be evaluated through field measurements if experience from the area is limited.

- temperature;
- sea water and mud resistivity;
- sea water velocity;
- pH;
- water pressure (depth) along the route;

- presence and quantity of $H_2S$ producing bacteria (e.g. SRB);
- water composition with particular reference to the oxygen content;
- presence of stray and/or telluric currents in the area (see 10.2).

## 4.5 Protective current density

One of the main parameters to be defined in the design of the cathodic protection system for a submarine pipeline is the current density required to protect the steel surface of the pipeline throughout all its design life.

Three values of current density are significant. The initial, maintenance and repolarization values which refer respectively to the current density required to polarize the pipeline within a reasonable time period (i.e. 1 to 2 months) the current density necessary to maintain the polarization and the current density necessary for an eventual repolarization which may occur for example after an heavy storm.

The selection of the design current densities may be based on experience from similar pipelines in the same environment or on field measurements carried out in the same area.

Due consideration should be given to the following:

- the current density demand is normally not constant with time; for bare steel areas of pipelines in seawater or the seabed the current density requirements may decrease due to the formation of calcareous deposits caused by the cathodic current;
- for coated areas of pipelines the current requirements may increase with time as the coating deteriorates.

Guidelines on the design current densities are given in annex A.

## 4.6 Selection of the cathodic protection system

Either sacrificial anode and/or impressed current cathodic protection system may be used to protect a submarine pipeline.

The selection between the two systems should be based on the following considerations:

- the impressed current system may only protect a finite length of pipeline, determined by the following:
    - practical limitations on the locations for impressed current system installations, e.g. the ends of the pipeline and intermediate platforms or landfalls,
    - the value of the insulation resistance of the coated pipeline versus the surrounding electrolyte at the end of its design service life (see annex C),
    - the longitudinal resistance of the pipeline (see annex C);
- the lack of a source of external power may preclude the use of impressed current systems;
- sacrificial anode systems do not require any operation control or maintenance during the service life of the pipeline;
- sacrificial anode systems seldom cause serious interaction problems on foreign neighbouring structures, whereas impressed current system may have a significant effect.

## 4.7 Electrical isolation

Electrical isolation between a submarine pipeline and other steel structures to which the pipeline is mechanically connected may be used in order to improve or verify the effectiveness of the relevant cathodic protection system.

Cases where insulating devices may be used are as follows:

- between the offshore and the onshore sections of the same pipeline;

- between a submarine pipeline and the platform where the pipeline starts and/or ends unless other constraints, such as safety requirements, dictate that an insulating device should not be installed.

If used the insulating devices shall be placed above the water and splash zone and in compliance with relevant regulations.

### 4.8 Electrical continuity

Electrical continuity is generally provided between the pipeline and any ancillary steel items by means of suitable connecting cables.

### 4.9 Test points

To check the performance of the cathodic protection on a submarine pipeline measuring cables and test points may be installed at both the ends of the pipeline if direct contacts are not possible.

For submarine pipelines protected by sacrificial anodes any permanent measuring devices along the pipeline route may be omitted but the extremities shall remain accessible either directly or by means of a measuring cable.

### 4.10 Miscellaneous

During the design stage of the cathodic protection system of a submarine pipeline all the interested parties in the area of the pipeline route should be notified of the proposed pipeline installation and the characteristics of the cathodic protection system.

Cooperative investigations should be carried out to determine the possible effect of the proposed pipeline cathodic protection system on the facilities of others in the proximity or area of the proposed pipeline.

## 5 Design of sacrificial anodes system

### 5.1 General

The sacrificial anodes system provides protection of the steel structure by connecting it to a more electronegative alloy.

Generally the sacrificial anodes are electrically connected to the pipeline by welding.

The sacrificial anodes system shall be designed to ensure that the protective potential criteria is achieved on the whole surface of the pipeline during its entire design life.

### 5.2 Selection of anodic material

The following types of anode materials may be used: alloys of aluminium, magnesium, or zinc.

The alloy selected shall be one that can be demonstrated by past field performance in similar conditions, or by laboratory and field trials in simulated equivalent conditions, to perform satisfactorily in accordance with prEN 12496:1996. The selection of anode composition is critical for effective performance in specific environments. 5.2.1 to 5.2.3 are a general guide only.

#### 5.2.1. Aluminium alloy anodes

Aluminium alloy anodes can be used in sea water or in the sea bed.

Aluminium based alloys have a decreased electrochemical efficiency at elevated temperature. Some alloys may not even be suitable when operated at elevated temperatures.

The behaviour of some aluminium alloys may be adversely affected when covered with mud and particularly at low current output.

Some alloys may suffer intergranular corrosion even at low temperatures.

Some alloys containing magnesium may suffer ageing with a loss of mechanical properties.

#### 5.2.2. Magnesium alloy anodes

Magnesium alloy anodes can cause very negative potentials usually beyond the negative limit and have a high practical consumption rate; however they may be used in special applications.

#### 5.2.3. Zinc alloy anodes

Zinc alloy anodes can be used in sea water or in the sea bed.

Zinc based alloys should be formulated to minimize the risk of intergranular attack.

Zinc alloys may undergo a reduction in driving potential and should not be used at temperatures exceeding 50 °C unless supported by appropriate test data.

Intergranular corrosion and/or a reduction of their current capacity may occur at elevated temperatures.

#### 5.2.4. Anode performance

The electrochemical properties of the anodic material include:

- the driving voltage to polarized steel i.e. the difference between closed circuit anode potential and the positive limit of the protective potential criteria;
- the practical current capacity (in ampere hour per kilogramme) or consumption rate (in kilogrammes per ampere per year);
- the susceptibility to passivation;
- the susceptibility to intergranular corrosion.

The main parameters which affect anode electrochemical properties are:

- anode exposure conditions (if immersed in sea water or buried in mud);
- chemical composition of anode alloy;
- temperature;
- method and procedure of fabrication.

The electrochemical properties of the anodic material should be documented or determined by appropriate tests approved by an independent body.

The environmental impact of the alloy should be taken into consideration.

### 5.3 Shape and dimensions of sacrificial anodes

Sacrificial anodes for submarine pipelines are typically half shell or segmented bracelet type, but other types may be considered.

Bracelet anodes shall be provided with suitable steel inserts to allow the assembly and tightening of the bracelet halves or segments around the pipe and to give adequate support to the anodic material.

The inserts should be located in such a way to achieve the design utilization factor (see annex B).

The dimensions of the anodes should be selected on the basis of the following:

- external pipe diameter;
- corrosion coating thickness;

- any restraints due to the anode fabrication process;
- suitability to the pipeline laying method and relevant equipment;
- weight coating thickness, if present;
- current output and life requirements (see 5.4).

For submarine pipelines without a concrete weight coating or with the external diameter of the bracelet greater than the external diameter of the concrete coated pipes, both ends of the bracelet anodes should be tapered to the pipeline or external surface of the weight coating. Practical foundry techniques may limit the extent of this taper.

### 5.4 Sacrificial anode design

The design of the sacrificial anode system should be based on the following: (see also annex B)

- the total amount of anode material shall be sufficient to protect the pipeline for the whole of the design life;
- the available current output of the anodes shall be higher than the current required to protect the pipeline during the service life;
- the anodes shall be spaced at intervals along the pipeline to ensure that the current delivered by the anodes is distributed effectively on the pipeline surface;
- on pipeline systems close to other steel installations (e.g. platforms, submarine structures etc.) additional anodes should be provided to take into account possible current drainage to other installations;
- at crossing with a previously installed pipeline the location of the anodes of both the pipelines close to crossing should be checked to prevent any significant reduction of the protection levels and/or any increase in the rate of anode consumption.

## 6 Installation of sacrificial anodes

### 6.1 Sacrificial anode assembly on pipes

The sacrificial anodes shall be mounted on the pipes in such a way as to avoid any slippage during pipeline laying and to maintain a reliable electrical connection to the pipeline.

Several methods may be used; typical methods employed for the assembly of half shell bracelet anodes include the fastening of the two halves of each bracelet anode around the pipe by welding together the coupling steel strip inserts of the bracelet anodes or by bolting together the two bracelet anode halves.

### 6.2 Electrical connection between bracelet anode and steel pipe

To provide electrical continuity between bracelet anode and the pipeline the following methods may be used:

- insulated copper cables welded or brazed to the anode inserts and the steel pipe;
- fillet welding of the anode insert to the pipe directly, or, preferably, to a doubler plate pre-installed on the pipe joint.

The connection between the insulated copper cable and the steel pipe may be carried out by the following two general methods: thermite welding and brazing.

The welding procedure should be qualified to ensure that the mechanical strength and the electrical continuity of the connection is adequate. It is also necessary to verify that the welding process does not affect the mechanical properties of the steel pipe and that it does not induce any cracks in the pipe wall.

### 6.3 Installation procedure

Bracelet anode installation should be carried out in such a way that any significant damage to the pipe coating beneath the anode is minimised.

The bracelet anodes shall be tightened with adequate compressive strength around the linepipe to avoid any slippage during the pipeline laying.

Where a connection cable is to be used each bracelet anode should be electrically connected to the pipe by at least two attachments and preferably two for each half of the anode.

Suitable bonding cables shall be installed in a way that minimizes the possibility of their mechanical damage.

Welding should not be within 150 mm of any pipe welds.

At cable-to-pipe or fillet welding connections corrosion protection coating should be properly repaired.

After each anode installation with cable connections the electrical resistance between the anode and the relevant pipe should be checked by a suitable technique to ensure adequate continuity.

Any steel reinforcement in the concrete weight coating should not be in electrical contact with pipe or anode.

### 6.4 Underwater installation

Only in exceptional cases, (e.g. the retrofit of a cathodic protection system or the use of remote anode assemblies, for example on small diameter pipelines) should the underwater installation of anodes, utilizing either mechanical fixing devices or welding connections, be carried out.

Welding should be performed in a dry environment.

Wet welding is not permitted on pipe walls. It should only be used on parts of the pipeline system where cracks and defects would not be significant (i.e. doubler plate, existing anode inserts and supports).

Mechanical fixing devices may not give reliable electrical connections for long term applications.

## 7 Design of impressed current systems

### 7.1 General

Impressed current cathodic protection systems applied to submarine pipelines may consist of one or more cathodic protection stations located at one or both the ends of pipeline or at intermediate landfalls or structures.

Each station consists of the following equipment:

- transformer - rectifier/s or direct current electric power generator/s;
- impressed current anodes;
- connecting cables and current distribution boxes where necessary.

Impressed current systems should not cause any detrimental effect on the integrity of other pipelines and/or structures existing in the same area (see clause 9).

### 7.2 Materials

Impressed current anode materials may be high silicon cast iron, mixed metal oxides activated titanium, platinum coated or clad niobium, tantalum or titanium, lead alloys, graphite, magnetite or scrap-steel.

See annex E for impressed current anode performance characteristics.

Rectifiers may be constant current, potential controlled or manually controlled.

Cables should be provided with insulation sheathing suitable for marine environment and an external jacket for adequate protection from mechanical damage.

The electrical connection between the anode and the anode cable should be watertight and mechanically sound.

### 7.3 Impressed current system sizing

The impressed current system should be capable of protecting the entire length of the pipeline with the number of installed cathodic protection stations provided with remote groundbeds.

The current output capacity of the cathodic protection station/s should be based on the attenuation curve equations of the pipeline (see annex C). These equations give the variation of the pipe-to-electrolyte potential and the variation of the line current along the pipeline when the current is drained from one or more points of the pipeline and discharged to earth at the same location.

The application of the attenuation curves requires the evaluation of the insulation resistance of the pipeline at the time of the highest current demand, which may be at the end of its design life when, it has the lowest value due to coating degradation, or may be at the time of peak operating temperature.

The transformer rectifier should have a current output at least 25 % over the current required for the protection of the pipeline during the whole of its service life.

The impressed current anodes may be buried onshore or laid on the sea bed.

The anode should be sized to provide a low electrical resistance in the cathodic protection current circuit in order that the output voltage of the transformer-rectifier at the maximum current output does not exceed 50 V for safety reasons.

The total anodic material weight shall be greater than the anodic material consumed during all its design life at the maximum current output of the transformer-rectifier.

In case of inert composite anodes (e.g. platinum coated titanium anodes) the anode operating voltage shall be lower than the breakdown voltage of the oxide film of the anode base metal.

The minimum distance of the anode from the structure should be selected to avoid the protective potential of the pipeline section close to the anode being beyond the negative limit of the protective criteria (see 4.1 and annex C).

The design anode current density should be lower than the maximum current density of the relevant anode material as determined in field applications and/or laboratory testing or as recommended by the manufacturer.

## 8 Installation of impressed current systems

### 8.1 General

The installation of impressed current cathodic protection systems should be carried out under the supervision of a cathodic protection specialist to verify that the installation is in accordance with the relevant drawings, specifications and procedures.

All installation work shall be strictly in accordance with all national applicable codes and regulations and this standard.

Before installation all equipment should be inspected to ensure that it is in accordance with the specifications and that it has not been damaged.

### 8.2 Transformer-rectifier

Transformer-rectifier cabinets shall be connected to the local earthing system by a low electrical resistance connection in order to comply with the applicable regulations.

## 8.3 Anode and cable

Cathodic protection stations located at the onshore end of pipelines comprise conventional groundbeds and buried cable runs between transformer-rectifiers and the pipeline and between transformer-rectifiers and groundbeds.

Alternatively the anodes and cables may be installed on or in the seabed depending on the environmental conditions, type of seabed, anticipated traffic in the area and depth of water.

Suitable measures should be taken to protect anodes and cables on the seabed from damage caused by dragging anchors, trawl boards, nets, wave action, etc.

Where cathodic protection stations are installed on offshore structures the anodes may be located on the sea bed remote from the structure. Adequate testing and bonding shall be undertaken to prevent interaction effects on the structure.

The anodes may be supported by foundations and, in some cases, non-metallic buoyancy tanks to minimize the possibility of being covered with mud.

The connections between conductors in the anodic circuit should be mechanically secure, electrically conductive and sealed to prevent moisture penetration and ensure electrical insulation from the environment.

For connections between electrical cables and pipeline see 6.2. At cable to pipe attachment points, the corrosion protection coating should be properly reinstated after welding or brazing.

## 8.4 Isolating joint

No welding operations shall be carried out close to insulating devices without shunting the isolating joints. The shunt shall be removed after welding.

In case of welding operations close to an insulating joint it is necessary to take care so that the heat developed during the welding does not cause any damage to the insulating materials.

## 8.5 Inspections and tests

Appropriate inspections and tests should be carried out to verify that the installation of the impressed current cathodic protection system has been properly carried out (see clause 11).

# 9 Commissioning of cathodic protection systems

## 9.1 General

To verify the performance of the cathodic protection system commissioning tests shall be carried out after installation.

A cathodic protection survey covering the entire pipeline should be performed within one year of laying the pipeline.

## 9.2 Additional requirements for galvanic anodes system

For the commissioning of the galvanic anodes system the survey should include the determination of the pipeline potential along all its entire length. Indicative measurements of anode current output carried out during the survey may give valuable additional information.

The potential survey should be carried out by a continuous measurement method along the pipeline route.

One or more of the following measurement techniques may be used:

1) reference electrodes installed:

- on a remote operated vehicle (ROV),

- on a submarine;

2) electrodes lowered from the water's surface.

Single potential measurements shall be taken at particular locations of the pipeline for calibration purpose.

The method used for the potential measurement survey should take into consideration, where necessary, the ohmic drops (IR) in the environment between pipeline and reference electrodes.

The ability of the survey method to detect localised areas of under-protection or coating damage is significantly affected by the proximity of the reference electrode to the pipe.

### 9.3 Additional items for impressed current system

For the commissioning of an impressed current cathodic protection system the following additional operations should be carried out in the sequence indicated:

- check the wiring to ensure correct polarity;
- switch on the transformer-rectifier(s) to supply direct current to the pipeline;
- monitor the pipeline potentials at the accessible test points until the required potential values are reached;
- after a month check the potential of the pipeline and readjust if necessary.

## 10 Control of interference currents

### 10.1 Mechanism of stray current corrosion

Stray current corrosion on submerged pipelines is caused by foreign direct current sources, not electrically bonded to the pipelines, which discharge current into the electrolyte through a metallic structure located in the same area of the pipeline. The pipeline may receive stray current along its route. At locations where the current discharges into the electrolyte corrosion may occur.

### 10.2 Detection of stray currents

Personnel should be made aware of the possible electrical or physical observations during potential surveys which could indicate interference from a neighboring source.

EXAMPLE:

- structure-to-electrolyte potential changes on the affected structure;
- localized pitting in areas near to or immediately adjacent to a foreign structure;
- breakdown of protective coatings in a localized area.

In areas where stray currents are suspected, appropriate tests shall be conducted including the close interval measurements of structure-to-electrolyte potentials along the pipeline.

### 10.3 General methods for resolving interference effects

As interference effects are individual in nature, the solution should be subject to the mutual satisfaction of all interested parties.

The following general methods may be applied:

- prevention of the pick-up or limitation of the flow of interfering current through a submerged metallic structure;
- removal of the detrimental effects of interfering current from a submerged pipeline by means of a metallic conductor connected to the return (negative) side of the interfering current source;

- counteraction of the effect of the interfering current by means of cathodic protection;
- removal or relocation of the interfering current source.

## 10.4 Specific methods for resolving interference effects

The following methods may be used individually or in combination but the actual methods used will depend on water depth and the accessibility of the pipeline to be able to conduct valid testing and the attachment of metallic bonds.

**10.4.1** Prevention of the pick-up or limitation of the flow of interfering current may be achieved by the following methods:

- adjustment of the current output from mutually interfering cathodic protection rectifiers;
- suitable location of the anodes for cathodic protection;
- careful routing of proposed pipelines;
- application of a high insulating coating to strategic area(s) to decrease the interference circuit conductance.

**10.4.2** Design and installation of metallic bonds between the affected structures which electrically conducts the interference current from the affected structure to the interfering structure and/or current source according to the following criteria:

- the attachment of metallic bonds can reduce the magnitude of protective potential if cathodic protection exists on the interfering structure. Supplementary cathodic protection may then be required on the interfering structure to compensate for this effect;
- a metallic bond may not perform properly in the case of a cathodically protected bare or poorly coated pipeline which is causing interference on a coated pipeline. A metallic bond may increase the interference current. Coating the bare pipe or installing local sacrificial anodes on the coated pipe may reduce the interference effects;
- the design of any metallic bond(s) between pipeline(s) shall take into account the possible movement of the pipeline(s).

**10.4.3** Cathodic protection current may be applied to the affected structure at those locations where the interfering current is being discharged. This discharge will usually occur at locations where the pipelines are in close proximity. The following criteria should be considered:

- the anodes should be placed immediately adjacent to that portion of the affected structure that is discharging current;
- either sacrificial or impressed current anodes may be used.

## 10.5 Method to indicate resolution of interference

The following method may be applied to indicate the resolution of interference currents:

- restoration of the original pipe-to-electrolyte potentials of the affected structure to those values which existed prior to the interference;
- the reliability of this method depends on making electrical contact with the pipeline and placing the reference electrode at the appropriate locations.

## 10.6 Construction practice to minimize interference problem

Adequate clearance from all foreign structures should be maintained.

There should be an adequate distance between foreign pipelines and the impressed current anodes.

All new pipelines should be installed in such a way as to minimize coating damage and avoid coating damage on existing pipelines.

## 11 Monitoring and surveying of cathodic protection system

### 11.1 General

The most widely accepted method of evaluating the effectiveness of cathodic protection on pipelines is by potential measurements (see 9.1).

Permanent monitoring test stations of the cathodic protection system on submarine pipelines may be installed at readily accessible locations such as platform risers and landfall. They are not usually installed on the submerged portions of the pipeline.

Divers can carry out potential measurements on submarine pipelines at discrete locations using suitable probes normally based on Ag/AgCl/sea water reference electrode.

The protection level of a pipeline should be assessed by determining the potential profile of all the pipeline route in accordance with a suitable procedure (see 9.1).

The reference electrode should be calibrated before and after carrying out each dive of such a survey.

During measurements the reference electrode is to be positioned as close to the pipeline as possible.

### 11.2 Periodic potential surveys

An initial potential survey should be carried out after the pipeline installation on the seabed and the energising of the impressed current cathodic protection system, where applicable. This survey may include anode current output and a visual inspection of the pipeline to check for any coating damage and debris or other objects which may adversely affect the cathodic protection. If necessary the survey may include a visual inspection of the anodes to check the extent of their depletion.

Local potential measurements should also be carried out on areas of unburied sections of the pipeline where the coating has been damaged.

If the potentials are within the acceptable range there is generally no need for any remedial action. Remedial measures should, however, be taken promptly when the surveys indicate that protection is no longer adequate.

Such measures may include:

- repairing, replacing or adjusting components of cathodic protection systems;
- provision of supplementary cathodic protection capacity i.e. installation of additional sacrificial anodes or impressed current systems;
- removal of debris and avoiding contact with foreign steel structures.

Once an adequate protective level has been confirmed by the initial survey of the pipeline, successive periodic inspections can to a large extent be concentrated on selected areas, such as any sections with coating damage and on areas where severe environmental loads and/or where stringent safety regulations exist.

The frequency and extent of periodic potential surveys should be dependant on results from previous surveys. For risers annual visual inspection combined with potential measurements should normally be carried out.

Survey periods greater than one year may be adequate for well protected pipelines.

# 12 Safety

## 12.1 Introduction

This clause deals with safety hazards due to cathodic protection systems and related to diving personnel during their underwater operations.

The safety aspects are outside the scope of this document. Reference should be made to any appropriate statutory regulations (see annex D).

The following main dangers may be caused by the cathodic protection system (generally limited to an impressed current type): physical obstruction, electric shock and evolution of dangerous gas.

## 12.2 Physical obstruction

The major risk from anodes is the entanglement of the divers umbilical or life line around the anodes or the anode supports.

Therefore the anodes and the anode supports should be designed to exclude any sharp edges or corners or protruding assemblies.

## 12.3 Electric shock

In the event that the impressed current cathodic protection system equipment is defective, or the diver inadvertently makes direct contact with the active anode element, he may suffer an electric shock.

During diving operations not directly related to cathodic protection system, and any diving inspection carried out close to impressed current anodes, the DC supply of anodes shall be switched off. However, diving cathodic protection inspection may be performed, with the impressed current system in operation, providing all relevant safety regulations and precautions are applied (see annex D).

## 12.4 Gas evolution

### 12.4.1 Hydrogen evolution

Polarisation of the structure to potentials more negative than -0,80 V against Ag/AgCl/sea water reference electrode can result in the evolution of hydrogen gas at the steel surface. If the gas is allowed to collect in confined air spaces, it may present a risk of explosion. To avoid this hazard following measures should be taken:

- all designs shall include an adequate venting to prevent the build up of hydrogen;
- the structure-to-electrolyte potential shall be kept at potentials less negative than the threshold value at which the hydrogen evolution is not significant. This can be achieved by ensuring that a minimum distance is kept between the structure and impressed current anodes;
- magnesium alloy anodes should not be installed in areas where hydrogen build up may occur.

### 12.4.2 Chlorine evolution

Electrochemical reactions at the surfaces of impressed current anodes in sea water result in the evolution of chlorine gas, which is highly toxic and corrosive.

If this gas is allowed to collect in confined spaces, it may present a hazard to personnel and material.

To avoid this hazard, all designs shall prevent the build up of gas.

# 13 Documentation

## 13.1 General

The following documents and records should be maintained and updated, when applicable, during the lifetime of a submarine pipeline.

## 13.2 Design and installation

The design report on the cathodic protection system should include design criteria, basis and calculations.

In addition the following information should also be included:

a) for sacrificial anodes systems:

- specification, drawing and data sheets for the manufacture of the sacrificial anodes and the electrochemical test data;

- specification, drawing and data sheets for sacrificial anode installation;

- method of sacrificial anode attachment;

b) for impressed current systems:

- layout drawing of the cathodic protection stations including the location of test points;

- specifications and data sheets of all the necessary equipment i.e. transformer-rectifier, impressed current anodes and relevant supports, electric cables and their protection devices, test points, etc.;

- instructions for the installation of the cathodic protection system;

- instructions for the start up and commissioning tests;

c) the as-built documentation which should reflect any change from the design documentation;

d) the operation and maintenance instructions and recommendations for each component and for the whole cathodic protection system.

## 13.3 Commissioning and surveying

The commissioning documentation should include the results of the initial cathodic protection survey carried out after the installation of the submarine pipeline and after the energizing of the impressed current power sources. This is necessary to verify the effectiveness of the cathodic protection system and its capability to protect the pipeline as required.

The survey results should include the pipeline-to-electrolyte potential profile along the pipeline, anode current outputs for sacrificial anode system and transformer-rectifier current and voltage outputs for impressed current systems.

The commissioning documentation should also include the results of the tests and details of any remedial action carried out to eliminate or attenuate interference currents.

# Annex A
(informative)

## Guidance on current requirements for cathodic protection of pipeline and risers

In the absence of any other documented experience, the values in the following tables may be considered.

The selection of the design current density requirements ($i$) for the cathodic protection of steel submarine pipeline is carried out through the following two steps:

- determine the current density requirements for bare steel($i_0$) in milliampere per square meter

- define the extent of coating breakdown ($p$)

$$\text{where } p = \frac{\text{current density for coated steel } (i)}{\text{current density for bare steel } (i_0)}$$

Tables A.1, A.2 and A.3 give guidelines for the current density on bare steel exposed to sea water, current density on bare steel buried in the seabed and coating breakdown respectively.

**Table A.1 — Design current densities for cathodic protection of bare steel exposed to sea water at ambient temperature**

| | Current density (mA/m$^2$) | | |
|---|---|---|---|
| **Geographical areas** | **Initial value** | **Maintenance value** | **Repolarization value** |
| North Sea (northern sector): above 62 °N | 220 | 100 | 130 |
| from 55°N to 62 °N | 180 | 90 | 120 |
| North Sea (southern sector) below 55 °N, West U.K., West Ireland, Netherlands | 150 | 90 | 100 |
| Arabian Gulf, India, Australia, Brazil, West Africa | 130 | 70 | 90 |
| Mediterranean Sea, Adriatic Sea, Gulf of Mexico, Indonesia | 110 | 60 | 80 |

The values shown in Table A.1 should be adjusted, if necessary, to take into consideration the variation of the oxygen content in sea water with the depth.

**Table A.2 — Design current density for cathodic protection of bare steel buried in the seabed at ambient temperature**

| | Current density (mA/m$^2$) | | |
|---|---|---|---|
| **Geographical areas** | **Initial value** | **Maintenance value** | **Repolarization value** |
| All geographical areas | 25 | 20 | 20 |

For hot steel surfaces the above values should be increased by 1 mA/m$^2$ for each degree above 25 °C. Temperatures below 25 °C are considered ambient.

The design current densities of Table A.1 and Table A.2 are applicable also for cathodic protection of bare stainless steel both austenitic and austenitic-ferritic.

Taking into consideration the high number of factors which may affect the coating breakdown, the values shown in the Table A.3 are to be considered largely indicative and conservative. For any particular pipeline project cathodic protection design values should be selected on the basis of proper referenced documentation or service experience with similar projects.

**Table A.3 — Coating breakdown criteria for 30 year lifetime**

| Coating system | Coating breakdown % | |
|---|---|---|
| | Average | Repolarization |
| . Three layer system polyethylene or<br>. Three layer system polypropylene<br>. One layer system fusion bonded epoxy combined with barrier coating<br>All with concrete weight coating | 2 to 5 | 5 to 10 |
| Asphalt or coal tar enamel coating plus concrete weight coating | 4 to 6 | 6 to 12 |
| Polyethylene or polypropylene, three layer system, without concrete weight coating | 4 to 6 | 6 to 12 |
| Fusion bonded epoxy, liquid epoxy or polyurethane without concrete weight coating | 5 to 20 | 20 to 40 |

The values given in Table A.3 refer to both seawater exposed and buried in the sea bed. They are strongly influenced by the quality of the coating system as applied, coating of field joint and method of pipeline installation.

For design lives greater than 30 years the following annual increases in breakdown are applicable for all the above mentioned coating systems:

- 0,2 % for average coating breakdown;
- 0,4 % for final coating breakdown.

# Annex B
(informative)

# Anode sizing calculations

## B.1 Anodes life duration

The anode life $L$ is determined by the following relationship:

$$L = \frac{wu}{E \cdot I_m}$$

where:

$L$ is the effective life of the anodes, in years;

$w$ is the net mass of the anodes, in kilogrammes;

$u$ is the utilization factor. It is determined by the proportion of anodic material that may be consumed before the anode ceases to provide the required current output. The shape of the anode will affect the utilisation factor which may be in the range of 0,70 to 0,95. Typical utilization factor for bracelet anodes is 0,80;

$E$ is the consumption rate of the anode, in kilogrammes per ampere per year;

$I_m$ is the maintenance current output per anode during the lifetime, in amperes.

## B.2 Anodes current output

The current output of the anodes is given by the Ohm's law:

$I = \Delta V / R_1$

where:

$\Delta V$ is the driving voltage = anode close circuit potential - polarized steel potential, in volts;

$R_1$ is the circuit resistance (usually taken as the anode resistance), in ohms.

The following formula is mainly used to calculate resistance of bracelet type anodes:

$$R_a = \frac{0{,}315\rho}{\sqrt{A}}$$

where:

$A$ is the exposed surface area of anode, in square metres;

$\rho$ is the environment resistivity, in ohms metres.

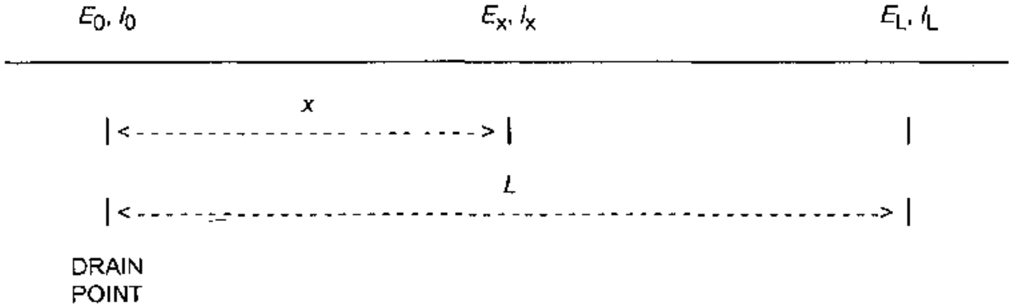
# Annex C
(informative)

## Attenuation curves

The attenuation curve method may be used as an approximate check on the suitability of the anode distribution once the cathodic protection system has been designed by conventional means, that is, using the data in Annex A and B.

This method is based on the attenuation curve formulas which provide the change in pipe-to-electrolyte potential and the line current at each point of the pipeline when the current is drained from one or more single points of the pipeline and discharged into the electrolyte.

In the general case of a uniform section of a pipeline:




The attenuation curves equations are:

$$E_x = E_0 \cosh \alpha x - R_k I_0 \sinh \alpha x \qquad E_0 = E_x \cosh \alpha x + R_k I_x \sinh \alpha x$$

or

$$I_x = I_0 \cosh \alpha x - \frac{E_0}{R_k} \sinh \alpha x \qquad I_0 = I_x \cosh \alpha x + \frac{E_x}{R_k} \sinh \alpha x$$

In case of a finite uniform line which terminates with an insulating device so that $I_L = 0$ or having multiple drain points at spacing of $2L$, which may be considered as several finite lines with the ends at the electrical mid point i.e. where zero current flows, the attenuation equations result:

$$E_x = E_0 \frac{\cosh \alpha (L - x)}{\cosh \alpha L}$$

$$I_x = I_0 \frac{\sinh \alpha (L - x)}{\sinh \alpha L}$$

where:

$x$ is the distance of point x from the drain point, in metres ;

$L$ is the length of the section of the pipeline, in metres;

$R_k$ is the characteristic resistance of the section, in ohms;

$$R_k = \sqrt{R_l \times R_t}$$

$R_l$ is the longitudinal or pipe linear resistance of the section, in ohms per metre;

$$R_l = \rho / S$$

$R_t$ is the leakage or transversal resistance of the section, in ohms metres;

$$R_t = \frac{R_0}{\pi \cdot D}$$

$R_0$ is the pipe-to-electrolyte insulation resistance, in ohms square metres;

$\rho$ is the specific resistance of steel, in ohms metres;

$D$ is the external diameter of pipeline, in metres;

$S$ is the section of line pipe wall, in square metres;

$\alpha = \sqrt{\frac{R_l}{R_t}}$ is the attenuation constant of the section, in metres$^{-1}$;

$E_0$ is the pipe-to-electrolyte potential at drain point, in volts;

$E_x$ is the pipe-to-electrolyte potential at point x, in volts;

$E_L$ is the pipe-to-electrolyte potential at the end of line, in volts;

$I_0$ is the current at drain point, in amperes;

$I_x$ is the current following in the pipe at point x, in amperes;

$I_L$ is the current entering in the pipe at the end of line, in amperes.

For design purposes an insulation resistance value $R_0$ is selected on the basis of the following main factors:

- type of coating;
- medium (sea water or sediments) to which the pipeline is exposed;
- design life of pipeline (due to reduction of coating insulation resistance with time);
- pipeline laying method (due to its influence on coating damage).

NOTE $R_0$, the pipe/electrolyte insulation resistance (often referred to by its inverse term, coating conductance) is critical to the accurate application of the attenuation calculations.
Measured values are not widely available for submarine pipelines and it is necessary to make significant assumptions to apply these calculations.

# Annex D
(informative)

## Safety precautions for impressed current system

Any applicable statutory regulation shall apply.

The following general information shall be considered.

Unless the step-down transformer is a double-insulated isolating type transformer, it should be fitted with protective devices which operate in the event of fault between the AC input of the transformer and the DC output of the rectifier.

Some typical electrical characteristics for impressed current anodes are given in annex E.

Based on the maximum current delivered by an anode, the resulting voltage gradient in the surrounding water can be calculated using the conductivity of the sea water, which can in turn be used to estimate the current likely in the divers body, assuming the worst case.

IEC/TR2 60479-1, IEC/TR 60479-2, IEC/TS 60479-3 (see bibliography) curves give the relationship between shock duration and allowable current passing through the body.

Considering the worst case of a safe body current of 40 mA as acceptable, the maximum safe voltage gradient without DC trip device will be 30 V maximum corresponding to a nominal voltage of 24 V.

This value is applicable for divers who may approach impressed current anodes and are normally wearing a complete rubber suit including rubber gloves.

In this case, the body resistance is considered to be of 750 Ω if the voltage remains inferior to 50 V (500 Ω for higher voltages).

Values of the safe distance from diver to anode in water i.e. with drop voltage inferior to 30 V depend on the ratio of delivered current ($I_a$) to the safe body current ($I_b$).

For divers who are not involved in or not aware of cathodic protection (such as for marine growth cleaning), it is recommended that the impressed current system is switched off during diving.

For divers involved in cathodic protection inspection, a safe distance to be kept between divers and impressed current anodes which are in operation.

For the performance of close visual inspection of impressed current anodes, the DC supply of anodes should be switched off.

# Annex E
(informative)

## Typical electrochemical characteristics for commonly used impressed current anodes

| Anode materials | Consumption rate (g/Ay) | Maximum current density ($A/m^2$) | Maximum voltage (V) |
| --- | --- | --- | --- |
| Platinised Titanium | 0,004 to 0,0012[a] | 500 to 3000 | 8[b] |
| Platinised Niobium | 0,004 to 0,0012[a] | 500 to 3000 | 50 |
| Platinised Tantalum | 0,004 to 0,0012[a] | 500 to 3000 | 100 |
| Mixed Metal Oxide | 0,0006 to 0,006 | 400 to 1000 | 8[b] |
| Lead Silver[c] | 25 to 100 | 250 to 300 | 24 |
| Chromium silicon iron | 250 to 500 | 10 to 30 | 50 |

[a] The life of the platinum film may be affected by the electrolyte resistivity, the consumption rate increasing with resistivity. The life of the platinum film can also be affected by the magnitude and frequency of the ripple present in the DC supply. Ripples frequencies less than 100 Hz should be avoided.

[b] In sea water, the oxide film on titanium may break down if the voltage at the anode exceeds 8 V vs Ag/AgCl/sea water. Higher voltages may be used with fully platinised anodes or in less saline environments.

[c] $PbO_2$ film formation may be enhanced by the use of Platinum pins in the lead silver alloy.

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[6] IEC/TR2 60479-1 (1994-09), *Effects of current on human beings and livestock - Part 1: General aspects.*

[7] IEC/TR 60479-2 (1987-03), *Effects of current passing through the human body - Part 2: Special aspects.*

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