BRITISH STANDARD

BS EN 13174:2001

Cathodic protection for harbour installations

The European Standard EN 13174:2001 has the status of a British Standard

ICS 77.060; 93.140

National foreword

This British Standard is the official English language version of EN 13174:2001.

Reference should also be made to BS 7361, Code of practice for land and marine applications, which will eventually be withdrawn when all the CEN Standards relating to cathodic protection currently being prepared, are published.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 Committee, was published under the authority of the Standards Committee and comes into effect on 15 June 2001

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EUROPEAN STANDARD

NORME EUROPÉENNE

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EN 13174

January 2001

ICS 77.060; 93.140

English version

Cathodic protection for harbour installations

Protection cathodique des installations portuaires

Kathodischer Korrosionsschutz für Hafenbauten

This European Standard was approved by CEN on 6 July 2000.

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.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: rue de Stassart, 36 B-1050 Brussels

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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 July 2001, and conflicting national standards shall be withdrawn at the latest by July 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, is usually applied, together with protective coatings or paint to protect the external surfaces of steel harbour installations and appurtenances from corrosion due to sea water or saline mud.

Cathodic protection works by supplying sufficient direct current to the immersed external surface of the structure in order to change the steel to electrolyte potential to values where corrosion is insignificant.

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

1 Scope

This European Standard defines the means to be used to cathodically protect the immersed and buried metallic external surfaces of steel harbour installations and appurtenances in sea water and saline mud.

1.1 Structures

This European Standard covers the cathodic protection of fixed and floating structures. This essentially includes piers, jetties, dolphins (mooring and berthing), sheet or tubular piling, pontoons, buoys, floating docks, lock and sluice gates.

It also covers the submerged areas of appurtenances, such as chains attached to the structure, when these are not electrically isolated from the structure.

It does not cover the cathodic protection of fixed or floating offshore structures, submarine pipelines or ships.

This European Standard does not include the internal protection of surfaces of any components such as ballast tanks and internals of floating structures or the internals or back faces of sheet steel piling which is in contact with backfill.

1.2 Materials

This European Standard covers the cathodic protection of structures fabricated principally from bare or coated carbon manganese steels.

As some parts of the structure may be made of metallic materials other than carbon manganese steels, the cathodic protection system should be designed to ensure that there is a complete control over any galvanic coupling and minimise risks due to hydrogen embrittlement or hydrogen induced cracking (see EN 12473).

This European Standard does not cover concrete structures.

1.3 Environment

This European Standard is applicable to the whole submerged zone in sea water, brackish waters and saline mud which can normally be found in harbour installations wherever these structures are fixed or floating.

For surfaces which are alternately immersed and exposed to the atmosphere, the cathodic protection is only effective when the immersion time is sufficiently long for the steel to become polarised.

1.4 Safety and environment protection

This European Standard does not cover safety and environmental protection aspects associated with cathodic protection. The relevant national or international regulations shall apply.

2 Normative references

This European Standard incorporates, by dated or undated references, 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, *General principles of cathodic protection in sea water.*

prEN 12496, *Galvanic anodes for cathodic protection in sea water.*

3 Terms and definitions

For the purposes of this European Standard the terms and definitions in EN 12473 and the following apply:

3.1
atmospheric zone
zone located above the splash zone, ie. above the level reached by the normal swell, whether the structure is moving or not

3.2
buried zone
zone located under the mud line

3.3
Cathodic Protection zone
that part of the structure which can be considered independently with respect to cathodic protection design

3.4
extended tidal zone
zone including the tidal zone, the splash zone and the transition zone

3.5
H.A.T.
level of highest astronomical tide

3.6
immersed zone
zone located above the mud line and below the extended tidal zone or the water line at a draught corresponding to the normal working conditions

3.7
L.A.T.
level of lowest astronomical tide

3.8
M.T.L.
mean tide level (also known as M.S.L. or M.W.L.)

3.9
R.O.V.
remotely operated vehicle

3.10
piling
deep foundation tubular or sheet steel element forming part or whole harbour structure

3.11
splash zone
the height of the structure which is intermittently wet and dry due to the wave action just above the H.A.T

3.12
submerged zone
zone including the buried zone, the immersed zone and the transition zone

3.13
transition zone
zone located below L.A.T. and including the possible level inaccuracy of the structure installation which is affected by a higher oxygen content due to normal swell or tidal movement

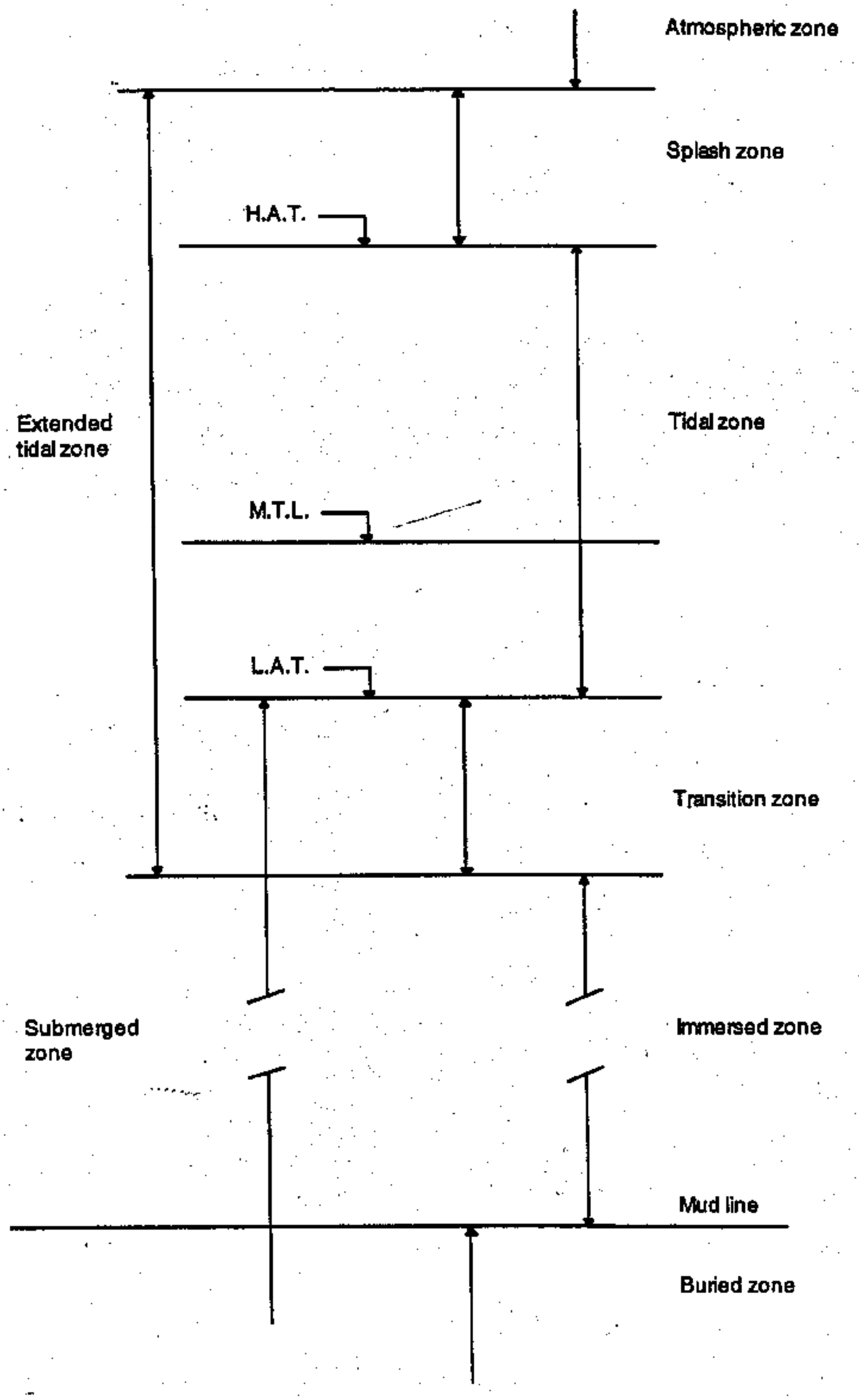

Figure 1 – Schematic representation of levels and zones in sea water environment

4 Design basis

4.1 Objectives

The major objective of a cathodic protection system is to deliver sufficient current to each part of the structure and appurtenances and distribute this current so that the potential of each part of the structure is within the limits given by the protection criteria (see 4.2).

Potentials should be as uniform as possible over the whole structure. This may be approached only by an adequate distribution of the protective current over the structure during normal service conditions, however it may be difficult to achieve in some areas such as chains, when a supplementary cathodic protection system should be considered.

The cathodic protection system for a fixed and floating structure is generally combined with a coating system, even though some appurtenances such as chains, may not benefit from the use of coatings. Extensive coating damage may also occur to buried areas of piling which is driven into position during installation.

Dielectric shields may be used in conjunction with anodes to minimise the risk of local over-protection.

The cathodic protection system should be designed either for the life time of the structure or for a period corresponding to maintenance or dry-docking interval. Alternatively when it is not feasible to design the cathodic protection system for the life of the structure or dry-docking is not possible, the system should be designed for easy replacement, typically using divers or R.O.V.

The above objectives should be achieved by the design of a cathodic protection system using impressed current or galvanic anode systems or a combination of both.

4.2 Cathodic protection criteria

The criteria for cathodic protection are detailed in EN 12473.

To achieve an adequate cathodic protection level, steel structures should have potentials as indicated hereafter.

The accepted criterion for protection of steel in aerated sea water is a polarised potential more negative than -0,80 V measured with respect to silver/silver chloride/sea water reference electrode (Ag/AgCl/sea water reference electrode).

However, steel immersed in solutions which contain active sulphate reducing bacteria (anaerobic conditions), because of the possibility of microbiologically induced corrosion, a potential more negative than -0,90 V (Ag/AgCl/sea water reference electrode) is generally recommended.

A negative limit of -1,10 V (Ag/AgCl/sea water reference electrode) is generally recommended for coated structures.

Where there is a possibility of corrosion fatigue, the negative limit should be more positive. This negative limit should be documented.

4.3 Design parameters

The design of a cathodic protection system should be made in accordance with the following parameters: structure subdivision, component description and service conditions.

4.3.1 Structure subdivision

Harbour structures to be protected can be divided into different Cathodic Protection zones, (CP zones), which can be considered independently with respect to cathodic protection design, although they may not necessarily be electrically isolated.

EXAMPLE 1 For a berthing dolphin, the area of piling can be divided into two main CP zones: the immersed or wetted CP zone and the buried CP zone. This division is related to the high current demand of the immersed or wetted CP zone due to the velocity of water movement, salinity, oxygen content and temperature. In the buried CP zone the current demand will be reduced due to the environment. There may be some specific elements which would not be included in a CP zone and therefore constitute a CP zone by themselves e.g. seawater intakes.

EXAMPLE 2 For buoys, a single zone is generally considered, sufficient to cover the body of the buoy and the influenced part of the mooring chain(s).

4.3.2 Description of CP zone

Each CP zone may consist of several components which should be fully described including material, surface area and coating characteristics (type, lifetime and coating breakdown factor).

4.3.3 Service conditions

The design of the cathodic protection system(s) will depend on service conditions which include: lifetime, environment and operating conditions.

- Lifetime: Either the whole design life of the structure, the dry-docking or maintenance period(s) should be considered.

- Environment: The sea water properties should be established (see EN 12473).

- Operating conditions: the cathodic protection design normally considers only the static conditions of the structure because the durations when dynamic conditions prevail are generally negligible.

4.4 Electrical current demand

4.4.1 General

To achieve the protection criteria for the conditions outlined in 4.3 it is necessary to select the appropriate current density for each component.

The current demand of each metallic component of the structure is the result of the product of its surface area multiplied by the required current density.

4.4.2 Protection current density for bare steel

The current density required may not be the same for all components of the structure as the environmental and service conditions are variable.

The selection of design current densities may be based on experiences gained from similar structures in a similar environment or from specific tests and measurements.

The current density depends on the kinetics of electrochemical reactions and varies with parameters such as the protection potential, surface condition, dissolved oxygen in sea water, seawater velocity at the steel surface, temperature.

The following should be evaluated for each design:

- initial current density required to achieve initial polarisation of the structure;

- maintenance current density required to maintain polarisation of the structure;

- final current density for possible repolarisation of the structure, e.g. after severe storms or cleaning operations.

As the initial polarisation preceding steady state conditions is normally short compared to the design life, the average current density over the lifetime of the structure is usually very close to the maintenance current density.

The (average) maintenance current density is used to calculate the minimum mass of the anode material necessary to maintain cathodic protection throughout the design life.

Typical values of current densities as used for bare steel are given in annex A.

4.4.3 Protection current density for coated steel

The cathodic protection system may be combined with suitable coating systems. The coating reduces current density and improves the current distribution over the surface.

The reduction of current density may be in a ratio of 100 to 1 or even more. However, the current density will increase with time as the coating deteriorates.

An initial coating breakdown factor related mainly to mechanical damage occurring during the fabrication of the structure and installation should be considered. A coating deterioration rate (i.e. an increase of the coating breakdown factor) should be selected in order to take into account the coating ageing and possible mechanical damage occurring to the coating during the lifetime of the structure or corresponding to the dry-docking or maintenance period(s).

These values are strongly dependent on the actual construction and operational conditions.

Guidelines for the values of coating breakdown factors (f_c) are given in annex A.

The current density needed for the protection of coated steel is equal to the product of the current density for the bare steel and the coating breakdown factor.

$$J_c = J_b \cdot f_c$$

where:

J_c is the protection current density for coated steel in amperes per square metres,

J_b is the protection current density for bare steel in amperes per square metres,

f_c is the coating breakdown factor which varies with time due to ageing and mechanical damage:

$f_c = 0$ for a perfectly insulating coating.

$f_c = 1$ for a bare structure.

This formula should be applied for each individual component or zone as defined in 4.3 where the coating, or the current density for bare steel, may be different.

4.4.4 Protection current demand

An evaluation of the current demand required should be carried out to optimise the mass and size of galvanic anodes, or the capacity of impressed current systems. The protection current demand I_e of each component of the structure to be cathodically protected is equal to:

$$I_e = A_e \cdot J_{ce}$$

where:

A_e is the surface area of the individual zone in square metres,

J_{ce} is the individual protection current density for the component considered in amperes per square metre.

The protection current demand I_z of each CP zone is therefore equal to the sum of current demand of each component included in the CP zone:

$$I_z = \Sigma_z(I_e)$$

where:

I_e is the protection current demand of each component included in the CP zone in amperes.

NOTE For current demand determination, the highest astronomical tide should be considered.

An estimate of the current demand of chains which are not electrically insulated from the structure should be made and added to I_z when applicable. This is necessary to ensure a safe cathodic protection design, even if the potential achieved on the chains (and their protection) will depend on the actual quality of the electrical continuity between the chains and the structure, and between the links of each chain.

4.5 Cathodic protection systems

Two types of cathodic protection systems are used:

- impressed current,
- galvanic anode.

Sometimes a combination of both systems is used (hybrid).

The choice of the most appropriate system depends on a series of factors (see EN 12473). In general, impressed current systems are preferred for structures fitted with electrical power and where there is a high current demand.

For any cathodic protection system, the size of the anodes shall be determined using Ohm's law.

$I := \Delta U / R$

where:

ΔU is the driving potential in volts,

R is the circuit resistance in ohms.

The anodic resistance is a function of the resistivity of the anodic environment and of the geometry (form and size) of the anode. Empirical formulae may be used such as those given in annex B for the evaluation of the anode resistance.

If the anodes are grouped in arrays and close to each other, mutual interference between anodes should be considered when calculating the anodic resistance.

The number and location of the anodes shall be determined in order to achieve as far as practicable an electrical current distribution leading to an adequate uniform protection potential level over the whole steel structure surface.

Calculations can be performed using computer numerical modelling based on finite elements or boundary elements methods.

All components of the cathodic protection system should be installed at locations where the probability of disturbance or damage is minimal.

4.6 Electrical continuity

It is essential that structures to be protected should be electrically continuous. Bonding of steel-piled structures, such as jetties or berthing dolphins should, where possible, be designed as an integral part of the structure. The bonding system may comprise of steel reinforcing bars of an electrically suitable size, cast into the concrete decking. To ensure good electrical continuity, the elements should be welded together or alternatively an external system of bonding should be used. Where relative movement between two parts of the structure is expected, e.g. at expansion joints and fenders, bonds need to be flexible. If cathodic protection is required for appurtenances, such as mooring dolphins, then electrical bonding to the structure should be ensured by appropriate means (submarine cables) except when protected by independent cathodic protection systems.

The electrical resistance of the bonding, should be low enough as practical, so as to obtain adequate protection of the structures connected.

The electrical continuity shall be permanently maintained.

For buoys and other moored structures no particular continuity device with anchor chains is generally required but continuity should be assessed.

4.7 Interactions

A structure may be permanently or temporarily connected to another neighbouring structures. Each structure should be fitted with its own cathodic protection system which should be checked before electrically connecting it to the floating structure under consideration.

If temporary connected foreign structures are not fitted with a cathodic protection system the potential of the structure being protected should be measured to confirm the protection is at an acceptable level during the period of connection.

Measurements should be taken to ensure that there are no deleterious effects of electrical stray current on the protected structure (see prEN 50162).

5 Impressed current system design

5.1 Objectives

An impressed current system provides protection using direct current (d.c.) delivered by connecting the steel structure to the negative terminal of an adjustable d.c. power source and the positive terminal to the anodes.

The electrical current output delivered by the d.c. power source is controlled during the expected lifetime of the cathodic protection system in order to obtain and maintain an adequate protection potential level over the whole steel surface of the structure.

The design calculations and specifications should include detailed information on the following:

- design basis,
- size of equipment,
- general arrangement of the equipment,
- specification of equipment, e.g. d.c. source, anodes, connection cables, terminations and protection devices, measurement electrodes,
- installation specifications,
- monitoring specification.

5.2 Design considerations

Impressed current systems for harbour structures usually includes one or more variable d.c. power source(s), several anodes and a number of fixed reference electrodes. For some installations portable reference electrodes may be used.

D.c. power sources with automatic potential control can be used when the environment conditions and the structure configuration and service conditions induce large and frequent variations of the current demand necessary to maintain polarisation.

Each CP zone (see 4.3.1) shall be protected by a dedicated system. Specific areas presenting particular situations may even require the consideration of a multi-zone control system in order to optimise the current distribution to the cathodic protection demand.

A dielectric shield is usually used around the anodes to prevent local over-protection and improve the current distribution to the cathode.

The total maximum current demand (I_z) for the protection of a CP zone of the structure should be calculated using formulae as per 4.4, with the most severe service conditions as described in 4.4.2 using the highest breakdown factor for the design life considered (see 4.4.3).

To compensate for a less efficient current distribution (small number of anodes), the cathodic protection system should be designed to be able to provide 1,1 to 1,5 times the calculated total maximum current demand, depending on the geometry and the coating of the structure:

$$I_t = (1{,}1 \text{ to } 1{,}5) \cdot I_z$$

5.3 Equipment considerations

5.3.1 Direct current power source

The d.c. power source shall be able to deliver the total maximum current (I_t) for the zone it is intended to protect.

The output voltage should take into account the resistance of the electric circuit (cables, anodes and back e.m.f.) and the maximum recommended operating voltage of the anodes.

The d.c. power source should be able to deliver sufficient electrical current to maintain the cathode potential within the set range.

D.c. power sources with automatic potential control should be able deliver an electrical current (constant or variable) when one of the reference electrodes used for the control of the d.c. power source leads to a potential reading less negative than the set positive limit (refer to 4.2 for the protection criteria).

This type of d.c. power source should also be able to deliver little or no electrical current when all the reference electrodes used for the control of the d.c. power source lead to potential readings more negative than the set negative limit.

There should be devices to limit the output current to each anode to a preset value.

D.c. power sources with output current limitation circuits should have an effective shut-down in the event of an external short circuit.

5.3.2 Anodes

Anodes should be either suitable for the life of the structure or replaceable. Anodes used for impressed current systems are generally of the "inert type". They are normally made of titanium, niobium or tantalum with a thin layer of platinum or mixed metal oxides which permit the discharge of electric current.

Lead silver semi-inert anodes can also be used provided that the initial anode current density is sufficient (20 A/m^2 to 50 A/m^2) to generate and maintain a conductive PbO_2 film. The performance of lead silver anodes may be affected adversely in deep water (> 30 m) or waters of low oxygen.

Chromium silicon iron semi-inert anodes may be used in buried conditions provided that the maximum anode current density is not higher than 30 A/m^2.

Typical electrochemical characteristics of impressed current anodes are given in annex C.

Generally impressed current anodes are of high current output and a small number are used compared to galvanic systems. Therefore the loss of an anode may significantly reduce the performance of the system. The anode assembly and its attachment should be designed to have a high resistance to mechanical damage.

All possible precautions shall also be taken in order to avoid any direct electrical contact (short circuit of the cathodic protection circuitry) between the anodes and the structure. Similarly, precautions shall be taken to avoid any leakage through the structure penetration.

It is usually a requirement to fit a cofferdam for floating structures.

The number, size and location of anodes should be determined in order to be able to deliver the electrical current distributed by the d.c. power source to which the anode are connected.

Additional calculations to assess the anodes distribution may be necessary.

5.3.3 Dielectric shields

Materials selected shall be suitable for the intended service. They shall be resistant to cathodic disbonding and to chemicals produced at the anodes.

Yard applied coatings, fibreglass reinforced plastic, prefabricated plastic or elastomeric sheets can be used on the structure adjacent to the anodes.

The design of the cathodic protection system should anticipate the possible deterioration and ageing of shielding materials and devices in order to obtain the desired life of the system.

5.3.4 Reference electrodes

Reference electrodes are used to measure the steel to sea water potential and are generally used to control the electrical current delivered by the cathodic protection system. These are either zinc or silver/silver chloride/sea water electrodes (see EN 12473). Zinc electrodes are more robust whereas silver/silver chloride/sea water electrodes are more accurate.

All precautions shall be taken to avoid any direct electrical contact between the electrodes and the structure. Similarly, precautions shall be taken to avoid any leakage of water through the structure penetration. It is usually a requirement to fit a cofferdam for floating structures.

The location of the reference electrodes is very important, particularly when used to control the system.

Electrodes should be installed at locations where the potential of the structure may become outside the protection criteria.

5.3.5 Cables and terminations

All connecting cables should be fitted with adequate protection to avoid any mechanical damage that could occur in normal service.

The electrical termination between the anode lead cable and the anode shall be watertight and mechanically secured.

The cable and termination insulation materials shall be resistant to their environmental conditions (chlorine, hydrocarbon and other chemicals).

When determining the cross section of the cable conductor, it is necessary to take into account the voltage drop for the length of cable under consideration.

The specified maximum current rating for a given size of cable should never be exceeded.

For potential measurements dedicated cables shall be used and these should be screened in order to avoid any interference.

6 Galvanic anode system design

6.1 Objectives

Galvanic anodes are manufactured from electromagnetic alloys which corrode to provide current and are connected directly to the steel structure.

The dimensions, number and location of the anodes should be determined so that the protection potential is achieved over the whole surface of the structure for the expected life of the cathodic protection system and under various service conditions.

6.2 Design considerations

The three design electrical current densities as defined in 4.4 shall be considered:

- the maintenance current density shall be used to determine the mass of the anodes. This current density is required to maintain an adequate polarisation level of the structure during its design life;

- the initial current density shall be used to verify that the output current capacity of the new anodes, i.e. their initial dimensions, is adequate to obtain complete initial polarisation of the structure;

- the repolarisation current density shall be used to verify that the output current capacity of the anodes when they are consumed to their utilisation factor, i.e. their final usable dimensions, is adequate to repolarise the structure after severe storms or marine growth cleaning operations.

Galvanic anodes are usually made of zinc, or aluminium based alloys.

Magnesium based alloys may be used for short term temporary or interim protection.

A large variety of shapes and sizes can be used to deliver protective electrical current in order to optimise the electrical current distribution.

The method of attachment of the anodes to the structure depends on their type and application but low resistance electrical contact shall be maintained throughout the operating life of the anodes.

Galvanic anodes should be preferably attached to the structure by continuous welding of their steel cores insert to the structure in such a manner that stresses are minimised at the weldment location. The anode insert may be bolted to separate supports which have been connected to the structure by continuous welding; a minimum of two bolts should be used at each support for attaching the anode. Attachment studs 'fired' into the structure are not permitted. Galvanic anodes may also be buried or immersed at a distance from the structure to be protected. Electrical continuity between the structure and the anode should be provided by with a suitably sized insulated cable protected against possible environmental and mechanical damage.

The performance of galvanic anodes in sea water depends essentially on the alloy composition.

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

The information required includes:

- the driving potential to polarised steel, i.e. the difference between closed circuit anode potential and the positive limit of the protection potential criterion,

- the practical electrical current capacity (A h/kg) or consumption rate (kg/A a),

- the susceptibility to passivation,

- the susceptibility to intergranular corrosion.

6.3 Factors determining the anode current output and operating life

The basic requirements for anodic materials are stipulated in EN 12496.

The environmental impact of alloy metal components released into the electrolyte should be taken into consideration.

The anode current output depends on the resistivity of the environment and on the anode shape and dimensions (see 4.3, 4.5 and annex B).

The anodic materials exhibit different specific consumption rates when operating in various environments.

Therefore, for a given current output, the anode life duration will depend on the anodic material (consumption rate) and its mass.

The dimensions and number of anodes should be optimised in order to minimise the total mass of the galvanic anodes, and in order to provide a protective electrical current greater or equal to the protective electrical current required for the permanent protection of the structure during the life of the anodes.

The cathodic protection system shall include sufficient mass of anodic material in order to be able to supply the (average) maintenance current demand during the design life of the system.

The output current is given by Ohm's law as explained in 4.5 and annex B.

The commonly used net driving potential between an anode made of a typical aluminium or zinc based alloy and a polarised or coated structure at its minimum cathodic protection level (-0,8 V vs Ag/AgCl/sea water) is only 0,15 V to 0,30 V.

Calculations can be performed using computer numerical modelling based on finite elements or boundary elements methods.

The anode life may be determined using the formula given in annex B.

6.4 Location of anodes

The galvanic anodes should be distributed to ensure the whole surface is polarised to within the recommended limits (see 4.2). It may be advantageous in some situations to use computer modelling based on finite elements or boundary elements calculation methods and/or model testing.

Galvanic anodes shall not be located in areas where they can interfere with the normal operation of the structure.

They should not be installed in high stress areas or areas subject to high fatigue loads such as butts or seams.

They should not be located in areas where they could be damaged (by accidentally dropped objects or by craft coming alongside, anchor chains or cables).

7 Cathodic protection system monitoring

Cathodic protection systems should be regularly monitoring.

Fixed monitoring systems are not essential for galvanic anode systems. However, fixed monitoring systems are essential for impressed current systems.

7.1 Objectives

The potential monitoring of a cathodic protection system should be able to follow and possibly control the operating parameters and the efficiency of the cathodic protection system.

Portable equipment used for periodic inspections is not included in the monitoring system. These may be used to verify the accuracy of the permanent reference electrodes and to measure potentials in critical areas that are not covered by permanent electrodes.

The steel to water potential should be measured periodically during the life of the structure in order to verify the adequacy of the cathodic protection system.

7.2 Potential measurements

7.2.1 Potential measurement method

The potential of steel is measured using a high impedance voltmeter connected to a reference electrode which shall be located as close as possible to the steel surface to be monitored.

If this measurement circuit remains permanently connected, care should be taken that it does not deliver current into the reference electrode which may become polarised and give false readings.

7.2.2 Location of reference electrodes

Some reference electrodes should be installed at locations representative of the average potential of each CP zone. Additional reference electrodes should be installed in areas where the potential of the structure is more likely to become outside set limits.

In the case of impressed current systems, reference electrodes should be fitted to the structure at suitable locations in order to control the output of the anodes and ensure critical areas are polarised to within the set limits.

7.2.3 Verification of reference electrodes

The reference electrodes shall be checked, i.e. calibrated at regular intervals by measuring their potential versus a saturated calomel reference electrode or versus any other reference electrode recently calibrated.

For installations where the reference electrodes cannot be dismantled from their permanent location, a portable reference electrode shall be used for their calibration. This should be placed in close proximity to the permanent reference electrode.

7.3 Measurement of impressed current anode electrical current output

The electrical current delivered to each anode should be measured at the corresponding output terminal of the rectifier or d.c. power source or at the distribution box as applicable.

7.4 Impressed current power source control

The d.c. power sources deliver the protective current to the anodes and should be equipped with the following control equipment:

- a voltmeter for the measurement of the d.c. output voltage,
- an ammeter for the measurement of the d.c. output intensity, possibly connected to a switch allowing the measurement of the electrical current output of each anode,
- protection devices against over-voltages and short circuits.

An hour meter can be installed for recording the operational periods of the d.c. power source.

8 Documentation

8.1 Objectives

All information, data and results related to the cathodic protection system should be recorded. This includes all data pertinent to the design, manufacture, installation, commissioning, operation and maintenance recommendations and effectiveness of the cathodic protection system.

The as-built documentation should reflect any changes from design specification. It essentially concerns the equipment location, deviation in water line which might alter protected areas.

Commissioning data should include results of surveys conducted after energising each cathodic protection system in order to confirm that it satisfies design criteria and operates effectively, including structure potential measurements to demonstrate that full protection is achieved.

8.2 Impressed current system

The following data should be kept for reference and regularly updated, if applicable:

- the design criteria including the design life, environment characteristics (e.g. water salinity range, resistivity), protection criteria, current density requirements and assumed values of anode output currents;
- the number of anodes, their size, specification, description of anodic equipment and connection, effective output current densities and permitted voltage, as well as the manufacturer/supplier data and documentation;
- the description and means of attachment of anodes, the composition and location of any dielectric shield (when applicable), as well as the specification, characteristics and attachment method and through wall or through hull arrangements of the connecting cables;
- the location of each anode as checked during construction, all deviations from the design location being highlighted and the date of installation. This data should be updated during the life of the structure;
- the location, detailed specification, drawings, and output characteristics of each d.c. power source (d.c. power source) with their factory test reports;
- the location, description and specification of any protection, potential control or monitoring device, including reference electrodes, measuring equipment and connecting cables;
- the commissioning results including potential survey data, current and voltage output values of each d.c. power source and any adjustment made for non-automatic devices;

- the data recorded during periodic maintenance inspection including protection potential values, d.c. output values, maintenance data on d.c. power sources and downtime periods in order to follow the changes of the protection potential level status of the structure.

8.3 Galvanic anodes system

The following data should be kept for reference and permanently updated, when applicable:

- design criteria including the design life, the environment characteristics (e.g. water resistivity), the protection criteria, current density requirements, assumed values of anode output currents at different periods and working conditions, and the anodes theoretical efficiency and driving potential;

- the number of anodes, their size, mass, specification, alloy composition, effective consumption rate, and characteristics, as well as the manufacturer/supplier references and documentation;

- the location of each anode as checked during construction, all deviations from the design location being highlighted, the method of attachment and the date of installation. This data should be updated during the life of the structure;

- the location, description and specification of any current or potential control or monitoring device, including type of reference electrode, measuring equipment, and connecting cables;

- the commissioning results including potential survey data;

- the results of periodic maintenance inspection survey data including current and protection potential measurements, equipment and the measuring technique in order to follow the changes of the protection potential status of the structure.

Annex A
(informative)

Guidance for current requirements for cathodic protection of harbour installations

In the absence of any other documented experience, the following values may be considered:

A.1 Design current densities for the protection of bare steel in sea water

Situation	Current densities (m A/m^2)					
	Initial value		Maintenance value		Repolarisation value	
	in poorly aerated waters	in well aerated waters	in poorly aerated waters	in well aerated waters	in poorly aerated waters	in well aerated waters
Static or semi-static conditions with tidal flow less than 0,5 m/s	80 to 100	120 to 150	50 to 65	65 to 80	60 to 80	80 to 100
Static or semi-static with tidal flow more than 0,5 m/s	120 to 150	170 to 200	60 to 80	80 to 100	80 to 100	100 to 130

A.2 Design current densities for the protection of bare steel in saline mud

Description	Current densities (m A/m^2)		
	Initial value	Maintenance value	Repolarisation value
All types of structures	25	20	20

A.3 Values of coating breakdown factors of usual paint systems for the design of cathodic protection systems

Initial coating breakdown factor: 1 % to 2 % in immersed areas

25 % to 50 % in buried areas

Depletion rate: 1 % to 3 % per year

NOTE Usual paint systems include minimum two layers of an ambient temperature cured paint (coal tar epoxy, epoxy, ..) with dry film thickness ranging from 250 µm to 500 µm.

Annex B
(informative)

Anode resistance and life determination

B.1 Anodic resistance (R_a) formulae

Slender anodes mounted at least 0,3 m offset from structure steel surface

if $L \geq 4r$

$$R_a = \frac{\rho}{2\pi L} \times \left[\ln\left(\frac{4L}{r}\right) - 1 \right]$$

if $L < 4r$

$$R_a = \frac{\rho}{2\pi L} \times \left\{ \ln\left[\frac{2L}{r} \times \left(1 + \sqrt{1 + \left(\frac{r}{2L}\right)^2} \right) \right] + \frac{r}{2L} - \sqrt{1 + \left(\frac{r}{2L}\right)^2} \right\}$$

Flat plate anodes

$$R_a = \frac{\rho}{2S}$$

Other shapes

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

where:

R_a is the anodic resistance in ohms,

is the environment resistivity in ohms metres,

L is the length of the anode in metres,

r is the radius of the anode (for other shapes than cylindrical, $r = \frac{C}{2\pi}$ where C is the cross section periphery) in metres,

S is the arithmetic mean of anode length and width in metres,

A is the exposed surface area of anode in square metres.

Without any information on the average resistivity of the environment, the following range of values can be used:

- cold sea water : 0,30 m to 0,35 m;
- warm sea water: 0,15 m to 0,25 m;
- saline mud: 0,70 m to 1,70 m.

For brackish water, the resistivity may fluctuate greatly (0,20 m to 10 m) depending on the salt content.

B.2 Anode life duration

The anode lifetime (T) may be determined using the following formula:

$$T = W \cdot u / (E \cdot I_s)$$

where:

- T is the effective lifetime of the anode in years,
- W is the net mass of anodes in kilogrammes,
- u is the utilisation factor determined by the portion of anodic material consumed when the remaining anodic material cannot deliver the current required. The shape of the anode will affect the utilisation factor which may be in the range of 0,7 to 0,95,
- E is the consumption rate of the anodic material in the environment considered, in kilogrammes per ampere and per year,
- I_s is the average (mean) current output during the life time in amperes.

Annex C
(informative)

Typical electrochemical characteristics of impressed current anodes

Anode materials	Consumption rate (g/A a)	Maximum current density (A/m^2)	Maximum voltage (V)
Platinised titanium	0,0012 to 0,004 [a)]	500 to 3000	8 [b)]
Platnised niobium	0,0012 to 0,004 [a)]	500 to 3000	50
Platinised tantalum	0,0012 to 0,004 [a)]	500 to 3000	100
Mixed metal oxide	0,0006 to 0,006	400 to 1000	8 [b)]
Lead silver	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 d.c. supply. Ripple 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. Higher voltages may be used with fully platinized or in less saline environments.

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