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BSI Standards Publication

Cathodic protection of ship hulls

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National foreword

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Cathodic protection of ship hulls

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Kathodischer Korrosionsschutz von Schiffen

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Foreword

This document (EN 16222:2012) 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of an identical text or by endorsement, at the latest by April 2013, and conflicting national standards shall be withdrawn at the latest by April 2013.

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Introduction

Cathodic protection is usually applied, mostly as a complement to protective coatings, to protect the external surfaces of ship hulls and immersed appurtenances from corrosion due to seawater.

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

1.1 General

This European Standard defines the general criteria and recommendations for cathodic protection of immersed external ship hulls and appurtenances.

This European Standard does not cover safety and environmental protection aspects associated with cathodic protection. Relevant national or international regulations and classification society requirements apply.

1.2 Structures

This European Standard covers the cathodic protection of the underwater hulls of ships, boats and other self propelled floating vessels generally used in seawater together with their appurtenances such as rudders, propellers, shafts and stabilisers.

It also covers the cathodic protection of thrusters, sea chests and water intakes (up to the first valve).

It does not cover the protection of internal surfaces such as ballast tanks.

It does not cover steel offshore floating structures which are covered in EN 13173.

1.3 Materials

This European Standard covers the cathodic protection of ship hulls fabricated principally from carbon manganese steels including appurtenances of other ferrous or non-ferrous alloys such as stainless steels and copper alloys, etc.

This European Standard applies to both coated and bare hulls; most hulls are coated.

The cathodic protection system should be designed to ensure that there is a complete control over any galvanic coupling.

This European Standard does not cover the cathodic protection of hulls principally made of other materials such as aluminium alloys, stainless steels or concrete.

1.4 Environment

This European Standard is applicable to the hull and appurtenances in seawater and all waters which could be found during a ship's world-wide deployment.

2 Normative references

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

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

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

EN 13509, *Cathodic protection measurement techniques*

EN 50162, *Protection against corrosion by stray current from direct current systems*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN ISO 8044, EN 12473 and the following apply.

3.1
immersed zone
zone located below the water line at draught corresponding to normal working conditions

3.2
underwater hull
part of the hull vital for its stability and buoyancy of a ship

Note 1 to entry: Part of the underwater hull might include that below the light water line.

3.3
boot topping
section of the hull between light and fully loaded conditions which may be intermittently immersed

3.4
cathodic protection zone
part of the structure which can be considered independently with respect to cathodic protection design

Note 1 to entry: A single zone may comprise a variety of components with differing design parameters.

3.5
submerged zone
zone including the immersed zone and the boot topping

3.6
driving voltage
difference between the structure/electrolyte potential and the anode/electrolyte potential when the cathodic protection is operating

3.7
closed circuit potential
potential measured at a galvanic anode when a current is flowing in between the anode and the surface being protected

4 Competence of personnel

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

EN 15257 constitutes a suitable method of assessing and certifying competence of cathodic protection personnel which may be utilised.

Competence of cathodic protection personnel to the appropriate level for tasks undertaken should be demonstrated by certification in accordance with EN 15257 or by another equivalent prequalification procedure.

5 Design basis

5.1 General

The objective of a cathodic protection system is to deliver sufficient current to protect each part of the structure and appurtenances and distribute this current so that the structure to electrolyte potential of each part of the structure is within the limits given by the protection criteria (see 5.2).

Potentials should be as uniform as possible over the whole submerged surfaces. This objective may only be approached by adequate distribution of the protective current over the structure during its normal service conditions. This may be difficult to achieve in some areas such as water intakes, thrusters, sea chests, where specific provisions should be considered.

The cathodic protection system for a ship is generally combined with a protective coating system, even though some appurtenances such as propellers are generally not coated.

Electrochemical anti-fouling systems are often used within sea chests to prevent fouling of seawater intake systems. The possibility of interaction between the anti-fouling system and the cathodic protection system should be considered in the design and installation of the anti-fouling system.

Cathodic protection within sea chests may adversely affect, by stray current interaction, box coolers in sea chests (typically copper nickel alloy tubes) if the box coolers are electrically isolated from the sea chest. The possibility of interaction should be taken into account in designing the cathodic protection requirements for the sea chest.

The cathodic protection system should be designed either for the life of the ship or on the basis of the dry-docking intervals.

The above objectives shall be achieved by the design of a cathodic protection system using galvanic anodes, an impressed current system or a combination of both.

The design, the installation, the energising, the commissioning, the long-term operation and the documentation of all of the elements of cathodic protection systems shall be fully recorded.

EN ISO 9001 constitutes a suitable Quality Management Systems Standard which may be utilised.

Each element of the work shall be undertaken in accordance with a fully documented quality plan.

Each stage of the design shall be checked and the checking shall be documented.

Each stage of the installation, energising, commissioning and operation shall be the subject of appropriate visual, mechanical and/or electrical testing and all testing shall be documented.

All test instrumentation shall have valid calibration certificates traceable to national or European Standards of calibration.

The documentation shall constitute part of the permanent records for the works.

5.2 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 follows.

The accepted criterion for protection of steel in aerated seawater is a protection potential more negative than – 0,80 V measured with respect to Ag/AgCl/seawater reference electrode. This corresponds approximately to + 0,23 V when measured with respect to pure zinc electrode (e.g. alloy type Z2 as defined in EN 12496) or

+ 0,25 V when measured with respect to zinc electrode made with galvanic anode alloy types Z1, Z3 or Z4 as defined in EN 12496.

A negative limit of – 1,10 V with respect to Ag/AgCl/seawater reference electrode is generally recommended in order to avoid coating disbondment and / or increase in fatigue propagation rates.

Where there is a possibility of hydrogen embrittlement of steels or other metals which may be adversely affected by cathodic protection to excessively negative values, an additional less negative potential limit shall be adopted. If insufficient documentation is available for a given material, this specific negative potential limit relative to the metallurgical and mechanical conditions shall be determined by mechanical testing at the limit polarised potential. For conventional steels, this limit is – 1,10 V (Ag/AgCl/seawater reference electrode). Refer to EN 12473 for more details.

The above potential criteria and limit values are "polarised" and are expressed without IR errors. IR errors, due to cathodic protection current flowing though resistive electrolyte and surface films on the protected surface, are generally considered insignificant in marine applications. Potential measurements using "Instant OFF" techniques or "coupon Instant OFF" techniques may be necessary in applications described in this European Standard in order to adequately demonstrate the achievement of the above protection criteria (see EN 13509). Particular attention should be given to this in brackish waters and close to impressed current anodes.

5.3 Design process

The design of a cathodic protection system shall be conducted according to the following different stages:

a) the structure is divided into various cathodic protection zones which will be considered independently with respect to cathodic protection design (see 5.4.2);

b) each component included in a cathodic protection zone is fully described (see 5.4.3);

c) the service conditions are well established (see 5.4.4);

d) the current demand is determined for each cathodic protection zone from (see 5.5):

   1) areas of components;

   2) current densities regarding the state of components and service conditions;

Two different approaches may be considered concerning the choice of current densities:

   3) From current densities of bare metal (see 5.5.2) introducing a breakdown factor for the coating (see 5.5.3) taking into consideration physicochemical ageing and mechanical damage versus time;

   4) From a global approach (see 5.5.3) based on experience.

When the first approach is selected, two types of current demands are determined (see 5.5.4):

   5) maximum current demand (I_{max});

   6) mean current demand (I_{mean}),

e) the cathodic protection system is determined for each cathodic protection zone (see 5.6);

f) an electrical continuity is planned between all components of a cathodic protection zone (see 5.7);

g) the appropriate cathodic protection system dedicated to a cathodic protection zone is designed (see Clauses 6 and 7).

NOTE The design of impressed current systems is based on maximum current demand. The design of galvanic anodes systems is based on maximum current demand and mean current demand.

5.4 Design parameters

5.4.1 General

The design of a cathodic protection system takes into consideration the following parameters: structure subdivision, components characteristics and service conditions.

5.4.2 Structure subdivision

The submerged surfaces of a ship hull can be divided into different cathodic protection zones which are then considered independently with respect to cathodic protection design although they are not electrically isolated.

For instance, the underwater hull can be divided into two main cathodic protection zones: the forward (or bow) zone and the aft (or stern) zone illustrated by the drawing in Annex A. This subdivision is related to the higher current demand of the aft zone due to high water flow rates, turbulence and the presence of dissimilar metals due to the propeller(s). The aft cathodic protection zone includes the following appurtenances: the aft part of the hull, propeller(s), shaft(s), rudder(s), etc.

Some specific components may constitute a cathodic protection zone by themselves (e.g. openings of sea chests, thrusters, rudders etc).

5.4.3 Components characteristics

Each component of a cathodic protection zone as mentioned above shall be fully detailed in the design including: material, specific potential limit (where applicable) area and coating characteristics (type, lifetime and coating breakdown factor).

5.4.4 Service conditions

The design of cathodic protection system(s) shall be related to the service conditions which include: lifetime, environment and operating conditions.

a) Lifetime

   Either the whole design life or dry-docking intervals should be considered.

b) Environment

   The characteristics of seawater should be established. Refer to EN 12473 General principles of cathodic protection in seawater. Particular attention is required for vessels anticipated to operate in ice conditions or estuarine/freshwater conditions.

c) Operating conditions

   The average and the maximum speeds should be considered combined with the percentages of lifetime associated to static (berthed) and dynamic (sailing) conditions.

5.5 Current demand

5.5.1 General

To achieve protection criteria for the conditions outlined in 5.2 it is necessary to select the appropriate design current density for each component with respect to the environmental and service conditions.

The current demand of each metallic component of the structure is the result of the product of its surface area multiplied by the protection current density for the bare steel and by the coating breakdown factor.

See Annexes B and C for design current density and anode resistance calculation guidance.

5.5.2 Design current density for bare steel

The selection of design current densities may be based either on experience gained from similar ships operating in a similar manner or from specific tests and measurements.

The protection current density of bare steels and other bare metals depends on the kinetics of electrochemical reactions. It varies with parameters such as the material, potential, surface condition, dissolved oxygen content in seawater, flow rate or speed, temperature.

For each particular environmental and service conditions mentioned in 5.4.4 c), protection current density shall be evaluated.

Typical values of design current densities as used for bare steel are given in Annex B.

5.5.3 Design current density for coated steel

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

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

An initial coating breakdown factor related mainly to mechanical damage occurring during the fabrication of the ships should be considered. A coating deterioration rate (i.e. an increase of the coating breakdown factor with time) should be selected in order to take into account the coating ageing and mechanical damage occurring to the coating during the design life of the ship’s cathodic protection system or a period corresponding to the dry-docking interval.

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

Guidelines for the values of coating breakdown factors are given in Annex B.

The design current density required for the protection of coated steel is equal to the product of the current density for bare steel (see 5.5.2) and the coating breakdown factor:

$$J_c = J_b \cdot f_c$$

where

J_c is the protection current density for coated metal in A/m^2;

J_b is the protection current density for bare metal in A/m^2;

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 coating with no insulation properties (equivalent to bare metal).

This formula should be applied for each individual component or cathodic protection zone as defined in 5.3 where the coating or current density for bare metal can be different.

A global approach for the estimation of the protection current density for coated structures may be considered when values for design parameters are well known from numerous past experiences. Where a global approach is considered an average value of this protection current density (J_g) is taken into consideration. Guidelines for values of current densities for a global approach are given in Annex B. If a “global approach” is taken for the design it shall be documented in detail regarding the class of vessel and service for which the global track record has been collected and the basis upon which the satisfactory cathodic protection performance has been evaluated.

5.5.4 Current demand

Unless a global approach is adopted for the design two different values shall be considered:

I_{max} : maximum current demand

I_{mean} : mean current demand

I_{mean} is used to calculate the minimum mass of galvanic anode material or life of impressed current anodes necessary to maintain cathodic protection throughout the design period.

I_{max} corresponds to the most severe working conditions (e.g. dynamic conditions, end of life coating breakdown factor and worst case environmental conditions) and is used to design the maximum current capacity of the cathodic protection system.

So, for each component these two protection current demands can be determined according to the following formulae:

$$I_{e\,\max} = S_e \,.\, f_{c\,\max} \,.\, J_{bd}$$

$$I_{e\,mean} = S_e \,.\, f_{cmean} \,.\, \left[t \,.J_{bd} + (1-t)\, J_{bs} \right]$$

where

$I_{e\,max}$: maximum protection current demand for a component (A);

$I_{e\,mean}$: mean protection current demand for a component (A);

S_e : area of the submerged zone (component under full load conditions including the underwater hull and boot topping) (m^2);

$f_{c\,max}$: maximum coating breakdown factor for the concerned period;

$f_{c\,mean}$: mean coating breakdown factor for the concerned period;

J_{bd} : current density for bare metal in dynamic conditions (A/m^2);

J_{bs} : current density for bare metal in static conditions (A/m^2);

t : fraction of time associated to dynamic conditions.

Consequently, for each cathodic protection zone, both values of protection current demand are given by the sum of the respective elements, i.e.

$$I_{\max} = \Sigma\, I_{emax}$$

$$I_{mean} = \Sigma\, I_{emean}$$

If a global approach is adopted, a unique current demand is considered for each cathodic protection zone.

$$I = J_g\ \Sigma\left(S_e\right)$$

5.6 Cathodic protection systems

Two types of cathodic protection systems are used:

— Impressed Current;

— Galvanic Anodes.

A combination of both systems may be used (hybrid).

The choice of the most appropriate system depends on a series of factors (refer to EN 12473).

For cathodic protection system using galvanic anodes, the optimum anode dimensions are determined using Ohm's law:

$$I = \Delta U\ /\ R$$

where

I is the current output in amps

ΔU is the driving voltage, in volts.

R is the circuit resistance, in ohms.

The circuit resistance is assumed to be approximately equal to the electrolyte resistance, which is called “anode resistance” as the cathode (structure) resistance to the electrolyte is generally very small.

The anode resistance is a function of the resistivity of the electrolyte [anode environment] and of the geometry (form and dimensions) of the anode. Empirical formulae may be used to calculate the anode resistance such as those given in C.1.

For an impressed current system, the DC output voltage of the power source shall be higher than the sum of the voltage drops in all the components of the circuit: cables, electrolyte (generally considered as the anode resistance) and the anode/cathode back EMF (i.e. the potential difference between anode and cathode in the electrolyte without current).

The voltage between anode and electrolyte should not exceed a maximum acceptable value depending on the material of the anode.

NOTE Recommended figures for maximum acceptable voltages are given in Annex H.

Minimum anodic current densities may be necessary in some cases (see Annex H).

The number and location of the anodes shall produce as far as practicable an electrical current distribution achieving the protection potential level over the whole steel structure surface.

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

Calculations may be performed using computer numerical modelling based on finite elements or boundary element methods; these are normally only justified in particularly complex or novel applications or in military naval vessels where other considerations may necessitate such modelling.

All components of the cathodic protection system shall be installed at locations where the probability of disturbance to ship operations or mechanical damage is minimal.

5.7 Electrical continuity

Cathodic protection is required for metallic appurtenances such as rudders, stabilisers, propellers, thrusters, etc; therefore electrical bonding to the hull shall be ensured by appropriate means except when the appurtenances are protected by independent cathodic protection systems. Bonding of corrosion resistant copper based alloys or stainless steel propellers or thrusters and provision of cathodic protection current to them is necessary in order to prevent damaging galvanic corrosion of the adjacent hull or increased wear rate of bearings due to fortuitous galvanic couples.

The electrical resistance of the bonding shall be sufficiently low as to ensure adequate protection of the appurtenances connected.

The electrical continuity shall be permanently maintained.

The propeller shaft shall be bonded to the hull by means of slip rings and brushes (see Annex D). An arrangement for measuring the in-service propeller shaft/hull voltage should be provided (see Annex E). Except if otherwise specified, a maximum value of 50 mV is acceptable.

Rudders and stabilisers shall be bonded by means of flexible cables connected to adjacent hull surface (generally by welded studs) (see Annex D).

5.8 Fitting out period

Precautions should be considered at the design stage to assure adequate protection during the fitting out period (see 9.1).

6 Impressed current system

6.1 Objectives

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

The electrical current output delivered by the DC power source (normally a transformer-rectifier) is controlled during the lifetime of the cathodic protection system in order to obtain and maintain an adequate protection electrochemical potential level over the whole ship's hull, incorporating all the cathodic protection zones protected by impressed current systems.

6.2 Design considerations

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

— design basis;

— sizing of equipment;

— general arrangement of the equipment;

- specification of equipment (power source, monitoring and control systems, anodes, connection cables and connection and protection devices, reference electrodes, etc);
- installation specifications;
- monitoring specification.

Impressed current cathodic protection systems for ships usually include one or more transformer-rectifier(s) along with multiple anodes and reference electrodes.

Transformer-rectifiers with automatic potential control are generally used because the environment conditions and the structure configuration and service conditions cause large and frequent variations of the current demand necessary to maintain polarisation.

When applicable, each cathodic protection zone (refer to 5.4.2) shall be protected by a dedicated system.

Specific areas presenting particular situations may require the consideration of a multi-zone control system in order to adapt and optimise the electrical current distribution to the cathodic protection demand.

A dielectric shield shall be used around the anodes to prevent localised over-polarisation and improve the electrical current distribution to the cathode.

The maximum protection current demand for a cathodic protection zone (I_{max}) should be calculated using formulae according to 5.5, based on the most severe service conditions as stipulated in 5.5.4.

To compensate for a less efficient electrical current distribution (due to a smaller number of higher current anodes), the cathodic protection system should be designed to be able to provide a current I_t which is at a minimum 25 % more than the calculated maximum protection current demand I_{max}, depending on the geometry and the coating of the structure.

$$I_t \geq 1{,}25 \cdot I_{\max}$$

The components of the impressed current system shall include:

- power source;
- monitoring and control systems;
- anodes;
- dielectric shields;
- reference electrodes;
- cables, connections;
- cofferdams;
- bonding.

6.3 Equipment considerations

6.3.1 Power source, monitoring and control systems

All power source, monitoring and control systems shall be housed in control cubicles. The cubicle shall be mounted to reduce the effects of vibrations to an acceptable level.

The equipment shall be equipped with an input isolator.

The transformer rectifier delivers the protective current to the anodes and shall be equipped with the following minimal monitoring and control equipment:

- a voltmeter for the measurement of the DC output voltage;
- an ammeter for the measurement of the DC output current, possibly connected to a switch allowing the measurement of the electrical current output of each anode;
- a monitoring panel allowing the measurement of potentials with each of the reference electrodes and the selection of controlling reference electrode(s);
- a regulation system for the potential settings of the controlling reference electrode(s);
- protection devices against over-voltages and short-circuits.

An hour meter may be installed for recording the operational periods of the DC power source.

Suitable control circuits shall be included to detect and control the conditions listed below:

- over polarisation of the hull or appurtenance;
- under polarisation of the hull or appurtenance;
- over current to anodes;

A remote warning indicating that one of these parameters is out of limit may be provided at the ship control centre to show that a system malfunction has occurred.

Provisions for automatic or manual recording of system parameters, including as a minimum, output voltage, total output current, individual anode current, and hull or appurtenance / reference electrode potential shall be provided.

The transformer-rectifier shall be able to deliver I_t (see 6.2) to the cathodic protection zone that it is intended to protect.

The transformer-rectifier output voltage shall take into account the resistance of the electric circuit (cables, anodes and back emf) and the recommended operating voltage of the anodes.

The AC ripple shall be limited to 100mV RMS (Root Mean Square) in order to limit impact on the wear rate of platinum coated anodes (see Annex H).

The transformer-rectifier shall have automatic control which automatically delivers variable electrical current in order that the steel to electrolyte potential measured by the reference electrodes used for the control is maintained within the protection limits (see 5.2).

In the event of a reference electrode fault, the system may be designed to automatically ignore the defective reference electrode signal or revert to a pre-set current value. In any case, the equipment should be designed to be switched off if the operator judges it to be necessary.

A facility to limit the output current to each anode to a maximum value shall be provided.

6.3.2 Anodes

Anodes should be designed for the design life of the ships but shall be replaceable units.

Anodes used for impressed current systems should be of the inert type.

Inert anodes are generally 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 alloys semi-inert anodes may also be used provided that the initial and mean anode current density is sufficient (20 A/m^2 to 50 A/m^2) to generate and maintain a conductive PbO_2 film.

Environmental considerations should be addressed where appropriate.

Typical electrochemical characteristics of impressed current anodes are given in Annex H.

Generally few anodes are involved for high current outputs. Therefore the loss of an anode may significantly reduce the performance of the system.

The anode assembly and its attachment shall be designed to have a high resistance to mechanical damage.

Anodes shall not be located in areas where they can cause problems in the normal operation of the ship.

Anodes should not be installed in high stress areas or areas subject to high fatigue loads.

Anodes should not be located in areas where they could be damaged (craft coming alongside, anchor chains or cables). They should be located at half minimum light ballast draught.

Precautions shall be taken in order to prevent any direct electrical contact (short-circuit of the cathodic protection circuitry) between the anodes and the structure. Similarly, precautions shall be taken to prevent any leakage at the through hull penetration.

The number, dimensions and location of anodes shall be determined in order to be able to deliver the maximum protection current demand I_{max} or the maximum current I_t distributed by the transformer-rectifier to which the anodes are connected and to achieve the cathodic protection criteria (see 5.2) for the entire cathodic protection zone protected by that cathodic protection system.

6.3.3 Dielectric shields

Materials selected shall be suitable for the intended service. They shall be resistant to cathodic disbonding and to corrosive chemicals produced at the anodes (notably nascent chlorine) and not be prone to significant deterioration or ageing. They should be supplied with documented satisfactory service experience or with appropriate data.

Additional coatings applied on the yard, fibreglass reinforced plastic, prefabricated plastic or elastomeric sheets may be used as dielectric shields. Dielectric shields may be constituted by a thick (e.g. 4 mm) primary shield generally provided with the anode and a secondary shield comprising a high cathodic disbonding resistance coating.

The sizing of dielectric shields shall be a part of the cathodic protection design. Dielectric shields shall be sized in order that the conventional hull coating does not suffer cathodic disbondment and the hull materials do not suffer hydrogen damage at maximum anode current output. This matter may require detailed testing and / or modelling and should be determined in part by the properties of the hull coating and hull construction materials. In absence of specific study and for conventional steels and well maintained coatings, the minimum distance between the anode edge and the conventional hull coating may be as given in Table 1.

Table 1 — Typical minimum distance from anode edge to conventional coating

Anode current output (A)	< 20	≥ 20 and < 50	≥ 50 and < 150	≥ 150 and < 300
Distance (m)	0,5	1	1,5	2

6.3.4 Permanent electrodes

Reference electrodes are used to measure the metal to seawater potential and are generally used to allow the control of the electrical current delivered by impressed current cathodic protection systems. Electrodes are generally zinc or silver/silver chloride/seawater (see EN 12473). Zinc electrodes are more robust whereas silver/silver chloride/seawater reference electrodes are more accurate.

All precautions shall be taken to prevent any direct electrical contact between the electrodes and the vessel. Similarly, precautions shall be taken to prevent any leakage of water through any penetration provided for the electrode. Cofferdams shall be used to facilitate the entry of the electrode cable into the interior of the vessel in a manner which ensures the mechanical integrity and water-tightness of the vessel.

Reference electrodes shall be installed at locations determined by calculation or experience to ensure the potential of the hull is maintained within the set limits.

Reference electrodes shall be replaceable.

Ag/AgCl/seawater reference electrodes are only accurate in undiluted seawater with a salinity of 3,5%. If used in water of other salinity the values indicated will be in error. Reference electrodes should be stable to their theoretical potential to within ± 10 mV (see EN 12473).

6.3.5 Cables and terminations

All connecting cables should be of mechanically and chemically robust construction and fitted with adequate support and protection to avoid any mechanical damage that could occur in service, including the most arduous environmental conditions anticipated during the design life of the cathodic protection system.

The electrical termination between the anode cable and the anode shall be watertight, chemically resistant and mechanically robust.

The cable and termination insulation materials shall be resistant to their environmental conditions (nascent chlorine, high pH, seawater, hydrocarbons 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. Consideration should be given to these cables being screened in order to avoid any electrical or radio frequency electrical interference to the measured potential signals.

6.3.6 Cofferdams

Cofferdams should be constructed of materials which are metallurgically compatible to the hull.

The manufacturing and fitting of cofferdams shall be in accordance with relevant international, national or classification society requirements (see Annex I).

NOTE An overview of the different equipment concerned is given in the drawing of Annex A.

7 Galvanic anodes system

7.1 Objectives

The objective of a galvanic anode system is to deliver sufficient current to protect those parts of the structure selected for protection and to distribute this current such that the cathodic protection criteria detailed in 5.2 are met for the designed life of the system.

For a galvanic anode system current shall be provided by a metal (e.g. alloys of aluminium, zinc or magnesium) of more electro-negative potential than the item to be protected.

The dimensions, number and location of the anodes shall be determined so that the protection potential is achieved on the whole surface of the considered cathodic protection zone for the design lifetime of the cathodic protection system and under the service conditions (see 5.2 and 5.5.4).

7.2 Design considerations

Galvanic anode systems shall be the subject of a detailed design.

The design shall, as a minimum, include the following:

a) detailed calculations;

b) detailed installation drawings;

c) detailed material specifications;

d) detailed method of achieving anode / structure continuity and calculation for design of fixings;

e) detailed method statements or specification for installation, testing, commissioning and operation;

f) acceptance criteria for the completed system.

Annexes B and C detail items that should be considered in the design.

The inner face of surface mounted galvanic anodes should be coated.

Galvanic anodes should be preferably attached by continuous welding of their steel insert to the structure in such a manner that stresses are minimised at the weld location. The welding of the anodes shall be performed in accordance with the requirements of the design code. The steel insert of the galvanic anodes may be bolted to separate supports which have been connected to the structure by continuous welding. An attachment to studs 'fired' into the structure is not permitted. Stud welding may be permitted. Low electrical resistance contact shall be maintained throughout the operating life of the anodes.

When low hydrodynamic resistance has to be considered, shapes and methods of attachment of anodes should be optimised accordingly.

7.3 Anode materials

Galvanic anodes shall be in accordance with EN 12496 and the design requirements.

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

The information that should be documented includes:

- the driving voltage, 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 yr),
- the susceptibility to passivation,
- the susceptibility to intergranular corrosion.

Galvanic anodes for use on ship hulls are usually made of zinc or aluminium based alloys. Aluminium alloys are not normally effective in fresh water.

7.4 Factors determining the anode current output and operating life

The anode electrical current output depends on the resistivity of the environment and on the anode shape and dimensions (see 5.4 and 5.6 and Annex C). The anodic materials exhibit different specific consumption rates when operating in various environments. Therefore, for a given electrical current output, the anode life will depend on the anodic material (consumption rate) and its weight.

The dimensions and number of anodes should be optimised in order to minimise the total weight of the galvanic anodes, to provide a protective electrical current greater or equal to the mean and max protection current demand required for the permanent protection of the ship during the life of the anodes and to provide adequate distribution.

The cathodic protection system shall include sufficient weight of anodic material in order to be able to supply mean protection current demand during the projected lifetime of the system. The dimensions and number of anodes shall be determined in order to insure the maximum protection current.

The commonly used net driving voltage between an anode made of a typical aluminium based alloy or zinc based alloy and a polarised or coated structure at its minimum cathodic protection level (- 0,8 V vs. Ag/AgCl/seawater) is only 0,20 V to 0,30 V.

Additional calculations may be performed using computer numerical modelling based on finite element or boundary element methods.

The anode weight in order to achieve the design life should be determined using the calculation procedure given in Annex C.

7.5 Location of anodes

The galvanic anodes shall be distributed to ensure the steel surface is polarised to within the recommended limits (see 5.2). It may be advantageous in certain situations to use computer modelling based on finite elements or boundary elements calculation methods and/or model testing.

The most efficient protection is achieved by the use of a large number of small anodes well distributed around the hull in accordance with the following:

- a defined amount of the anodes shall be fitted in the stern/rudder area. The anodes shall be located outside of the areas as illustrated in Figures G.1 and G.2 of Annex G;
- the remainder of the anodes shall be spaced along the length of the hull preferably along suitable flow lines in order to minimise drag. The anodes should be spaced evenly or in longitudinal groups but where they are grouped an allowance should be taken for the significant reduction in current output that results. They should not be attached to areas likely to sustain regular mechanical damage, e.g. in way of the anchor or wharf damage. Where a bilge keel is fitted then the anodes should preferably be attached on either side.

The anodes shall not be attached to bottom plating or large unsupported panels and preferably not directly to the shell plating within the major longitudinal strength sections.

Where anodes are to be attached to plating of fuel oil or oil cargo tanks or internally coated areas the use of doubler plates shall be addressed. If used, they shall be continuously welded to the hull.

Where anodes are to be fitted for the protection of bow thruster units they should be fitted as close as possible to the vulnerable areas but with due consideration to the water flow.

Where anodes are to be fitted within sea chests, consideration shall be given to stray current interference to other items included in the sea chest.

8 Commissioning, operation and maintenance

8.1 Objectives

The objectives of the commissioning, operation and maintenance of the cathodic protection system are:

— to ensure that the cathodic protection system functions in accordance with the intentions of the design at installation;

— to ensure that the cathodic protection system continues to perform in accordance with the design and that the ship's hull and appendages remain satisfactorily protected from corrosion over the life of the system;

— all measurements shall be in accordance with EN 13509; potential measurements shall be as 8.2.

8.2 Measurement procedures

The metal / seawater potential shall be measured using a high impedance (10 MΩ minimum) voltmeter connected to a measurement electrode. Measurement electrodes shall be located as close as possible to the steel/seawater interface being measured.

Measurement electrodes shall be installed at locations representative of the average potential (see also 6.3.4). Additional reference electrodes shall be installed in areas where the potential of the structure is more likely to change to beyond the set limits.

In the case of impressed current systems, reference electrodes shall 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.

If this measurement circuit remains permanently connected, care shall be taken that it does not draw excessive current (including when idle) from the reference electrode which may become polarised and give false indications.

8.3 Commissioning: Galvanic systems

For galvanic systems a survey of hull / seawater potentials shall be undertaken within 1 month of the installation. The survey shall be undertaken using a portable reference electrode to supplement any permanent monitoring provisions installed. The survey shall be sufficient in magnitude to ensure that the criteria in 5.2 selected at design stage are met at representative locations.

Ag/AgCl/seawater portable reference electrodes should only be used in undiluted seawater with a salinity of 3,5%. If surveys are undertaken in brackish water the use of Ag/AgCl/0.5M KCl electrodes should be considered; however galvanic anode systems designed to operate in open seawater should not be surveyed for commissioning purposes in brackish or fresh water. If the vessel is otherwise commissioned in brackish water the cathodic protection surveying for commissioning should be undertaken as soon as possible after the vessel is in undiluted seawater.

A repeat survey as above should be undertaken 1 month before the end of the Defect Liability Period (or guarantee) for the ship and its cathodic protection system or within 12 months of dry docking and anode replacement.

8.4 Commissioning: Impressed current systems

8.4.1 Visual inspection

The cathodic protection system and all its components shall be subject to a complete visual inspection within the dry dock confirming that all components and cables are installed properly, are labelled where appropriate and protected from environmental, human or animal damage.

In the dry dock the electrical isolation of the anodes from the hull shall be confirmed by electrical resistance measurement; the values shall be recorded. All cable circuits shall be checked for continuity and insulation and the polarity of the DC output shall be confirmed.

The anodes and reference electrodes shall be 100% visually inspected from the hull external to confirm that the installation is as detailed in the design documentation and that the anodes and electrodes have not been coated.

The dielectric shield shall be visually inspected to confirm that the installation is as detailed in the design documentation. The shield shall be tested for film thickness and for absence of defects (“holidays”) both in accordance with the documentation and the dielectric shield manufacturer’s recommendations.

All inspections and data shall be recorded on inspection and test plans accordance with the quality plan (see 5.1).

8.4.2 Pre-energising measurements

Prior to switching ON the cathodic protection system, as soon as possible after the vessel is floated out from the dry dock, pre-energising measurements shall be made and recorded in accordance with the quality plan (see 5.1) and shall include the following:

a) Hull and appendage/seawater potentials with respect to permanently installed reference electrodes;

b) Proving of any electronic data logging and/or data transmitting facility installation as part of the performance monitoring system.

8.4.3 Initial energising

The cathodic protection system shall be energised (switched ON) in accordance with the design requirements for initial polarisation. Measurements shall be made and recorded in accordance with the quality plan (5.1) and shall include the following:

a) The potential of the hull and appendages/seawater with respect to all permanently installed reference electrodes;

b) Confirmation of polarity: if any steel/seawater potential values shift in a positive direction they shall be investigated to determine any requirements for additional testing and/or remedial works;

c) The output voltage and current of all transformer rectifiers and the current of all individual anodes.

8.4.4 Performance assessment

Within 1 month of energising, a survey shall be undertaken using a portable reference electrode to supplement the permanent monitoring provisions installed. The survey shall be sufficient in magnitude to ensure that the criteria in 5.2 selected at design stage are met at representative locations.

Ag/AgCl/seawater portable reference electrodes should only be used in undiluted seawater with a salinity of 3,5%. If surveys are undertaken in brackish water the use of Ag/AgCl/0.5M KCl electrodes should be considered.

A repeat survey as above should be undertaken 1 month before the end of the Defect Liability Period (or guarantee) for the ship and its cathodic protection system or within 12 months of dry docking and anode replacement.

See 5.2 with respect to criteria and IR drop errors.

8.5 Operation and maintenance

8.5.1 General

The operation and maintenance and testing intervals and procedures shall be as recommended in the operation and maintenance manual (see 10.2 and 10.3) or as subsequently modified based upon performance of the system.

8.5.2 Galvanic anodes systems

For galvanic anode systems periodic performance assessment shall be undertaken. This will comprise potential measurements, in accordance with 8.2, at identified locations around the hull.

Following the commissioning testing in 8.3, further testing should be performed, typically between 9 and 12 months and then at intervals of 2 to 5 years subject to proven performance and planned dry docking intervals.

In addition, dependent on the type of vessel, location of anodes, and dry docking intervals, a visual inspection of the anodes may be undertaken by diver survey, including a full report and a video record of the work carried out. The survey should assess the consumption of the anodes, check for physical damage to anodes and check that the anodes are visibly secure. Any damaged, consumed or missing anodes should lead to a risk assessment of the protection level of the hull or appendages. If necessary, these anodes should be replaced. Particular attention should be given to potential surveys and diver inspection of sea chests.

8.5.3 Impressed current systems

For impressed current systems, the normal operation will include confirmation that the system is switched ON and that a record of the operation of the system is in place, recording any down time and confirming that all systems are functioning and all anode current outputs are similar to those settled during the previous assessment.

Overall monitoring and inspection procedures together with typical frequency of activity shall include:

— Measurement and recording of transformer-rectifier output total current and voltage (daily);

— Measurement and recording of hull steel/seawater potential with respect to fixed measurement electrodes (daily);

NOTE In brackish or fresh water instant OFF potential measurements are necessary for the accurate assessment of polarisation.

— Measurement and recording of anode current outputs (daily);

— Measurement of parameters from any other sensors installed as part of the performance monitoring system (as appropriate);

— Calibration of permanent reference electrodes (annually);

The measurement electrodes shall be calibrated at regular intervals not exceeding 1 year, by measuring their electrode/seawater potential versus a Ag/AgCl/0.5M KCl reference electrode or versus any other reference electrode recently calibrated.

For installations where the measurement electrodes cannot be dismantled from their permanent location, a portable reference electrode shall be used for their calibration. This shall be placed as close as possible to the permanent measurement electrode and the cathodic protection current should be switched off during the calibration procedure.

— A detailed representative survey of the entire structure using portable reference electrodes (after dry-docking or any major repair/refurbishment of the cathodic protection system and annually);

— The measurement of potential difference between anodes and the hull to verify the metal - metal isolation of anode to hull (as an investigative tool if an electrical short circuit is suspected);

— Impressed current systems can pose a risk to divers and are normally switched off during diving operations in their vicinity; if this is impracticable, divers shall be informed that the system is energised so that the necessary actions can be taken to ensure their safety.

8.5.4 Interaction testing

Interaction testing is not normally required in respect of ships due to their normal mobility. However, if a ship is laid up or is berthed for long or repeated periods alongside steel quays or jetties it is recommended that interaction testing should be undertaken in order to demonstrate that adjacent structures are not adversely affected by the cathodic protection system (see EN 13509 and EN 50162). Any changes to the adjacent structure/electrolyte potentials greater than those permitted in EN 50162 shall be investigated and corrected.

Adjacent structures fitted with cathodic protection should not have their protection levels changed beyond the levels indicated in 5.2 by the subject new cathodic protection system. Adjacent structures not fitted with cathodic protection should not have their corrosion potentials changed by more than +20 mV by the subject new cathodic protection system as defined in EN 50162.

Similarly, if a ship is laid up or berthed for long periods adjacent to a quay or jetty which is itself protected with cathodic protection, it is recommended that cathodic protection interaction testing should be undertaken to determine the effects on the ship's hull of the adjacent cathodic protection system.

8.6 Dry-docking period

Galvanic anodes shall be inspected and replaced if their consumption rate is such that the cathodic protection system would not be adequate for the full period to the next dry-docking.

For impressed current systems, insulating resistance of anodes and electrodes to the hull shall be measured. Measurements shall be carried out after having cleaned the periphery of anodes and electrodes in order to avoid an electrical continuity due to salt deposits. Insulating resistance should be more than 1 MΩ.

Values below 1 MΩ may be acceptable for performance but should be investigated as they indicate possible deterioration.

9 The protection of ships' hulls during fitting out and when laid up

9.1 Fitting out period

If cathodic protection is to be applied to a ship it is desirable that it is applied from the time of launching. Conditions in fitting-out berths are often severely corrosive and it becomes especially important to prevent the onset of corrosion and damage to hull coatings during this period because this could influence the effectiveness of the permanent scheme.

When it is intended that a ship shall be fitted with a galvanic anodes cathodic protection system in service, they should be fitted before launching in order to protect the hull during fitting out and until the first docking.

If cathodic protection in service is to be by impressed current, then temporary galvanic anodes may be suspended over the ship's side and bonded electrically to the hull (see Annex J); these anodes should be sufficient to provide full polarisation in accordance with this Standard. These anodes can be hauled on board if the vessel has to change berth, and lowered again on arrival at the new position.

9.2 Lay up period

If the duration of inactivity is not predictable, permanent hull-mounted galvanic anodes may not be suitable, since their replacement requires docking. The choice between suspended galvanic anodes and an impressed current system powered from a shore supply will be determined by accessibility of supply and whether occupation of a berth is anticipated. At permanent moorings, galvanic or impressed current anodes may be laid on the seabed provided the clearance between the anodes and the keel at low water is sufficient to avoid paint damage.

The initial setting of the correct current requires two or three potential surveys at intervals of a few days. Thereafter, surveys may be at intervals of several months, provided the water conditions remain stable and the operation of the cathodic protection system is stable.

The proximity of other vessels or structures and the need for interaction testing as detailed in 8.5.4 shall be addressed.

Vessels that are laid up and static for long periods (years) may be subjected to marine growth colonisation and microbially influenced corrosion (MIC). In these circumstances the protection criteria shall be as for anaerobic conditions as in Table 2 of EN 12473 with a minimum negative potential of -0,90 V Ag/AgCl/seawater and maximum negative potential of -1,10 V Ag/AgCl/seawater.

10 Documentation

10.1 Objectives

All information, data and results relevant to the cathodic protection system shall be recorded and retained.

This shall include all data pertinent to the design, manufacture, installation, commissioning, operation and maintenance recommendations and effectiveness of the cathodic protection system.

The as-built documentation shall reflect any changes from design specification including any variations in the equipment locations, deviations in water line which might alter protected areas, etc.

Commissioning data shall include results of surveys conducted after energising each cathodic protection zone in order to assess that each zone satisfies design criteria and operates effectively, including structure potential measurements to demonstrate that the protection is achieved and, in the case of laid up vessels, any interaction testing with respect to adjacent structures.

10.2 Impressed current system

The following data shall be maintained for reference and shall be updated, if and when changes are made to the system:

— The design criteria including the design life, the environment characteristics (i.e. water salinity range, resistivity, etc), the protection criteria, the current density requirements, the design values of the anode output current and associated power supply output voltage at maximum current and anticipated operating currents at minimum and maximum extent of coating breakdown.

— The number of anodes, their dimension, specification, anode element composition, connection details, anode current densities and voltages, maximum, average, minimum anode life, etc, along with as the manufacturer/supplier data and documentation.

— The description of the 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 confirmed and recorded during construction, all discrepancies with design location being highlighted (these locations can be conveniently recorded on a specific drawing of the structure), the date of installation. This data should be updated during the life of the structure.

— The location, dimensions, surface preparation, material, dry film thickness and inspection data recorded during the installation of all dielectric shields.

— The location, detailed specification, drawings, circuit diagrams and output characteristics of each DC power source (e.g. transformer rectifier) with their factory test reports.

— The location, description and specification of any performance monitoring and control system, electrical protection devices (fuses, circuit breakers, etc) reference electrodes, measuring equipment and connecting cables.

— The commissioning results including steel/seawater/reference electrode potential survey data from both fixed reference electrodes and from a representative survey of the entire structure using portable reference electrodes, current and voltage output values of each DC power source, calibration measurements for each fixed reference electrode and any adjustment made for non-automatic devices.

— The results of data recorded during periodic maintenance inspection including steel/seawater/reference electrode potential values, DC output values, maintenance data on transformer-rectifiers and downtime periods in order to follow the changes of the cathodic protection system status for the structure.

— An Operation and Maintenance Manual which shall detail the as-built system, inspection and testing procedures, inspection and testing intervals and provide a fault finding guide. The data detailed above may in addition be incorporated into this volume.

10.3 Galvanic anode systems

The following data shall be maintained for reference and shall be updated, if and when changes are made to the system:

— Design criteria including the design life, the environment characteristics (i.e. water resistivity, etc), the protection criteria, the current density requirements, the assumed values of the anodes output current at different periods and working conditions, and the anode’s documented ampere-hour capacity and open circuit potential.

- The number of anodes, their dimension, weight, specification, alloy composition, documented ampere-hour capacity measured during tests, in accordance with EN 12496 and other characteristics, as well as the manufacturer/supplier references and documentation.

- The location of each anode as checked during construction, all discrepancies with the design location being highlighted (these locations can be conveniently recorded on a specific drawing of the structure), the method of attachment, the date of installation. These data shall be updated during the life of the vessel.

- The location, description and specification of any current or potential control or monitoring devices, including reference electrodes, measuring equipment, and connecting cables.

- The commissioning results including potential survey data from both fixed reference electrodes (if any) and from a representative survey of the entire structure using portable reference electrodes.

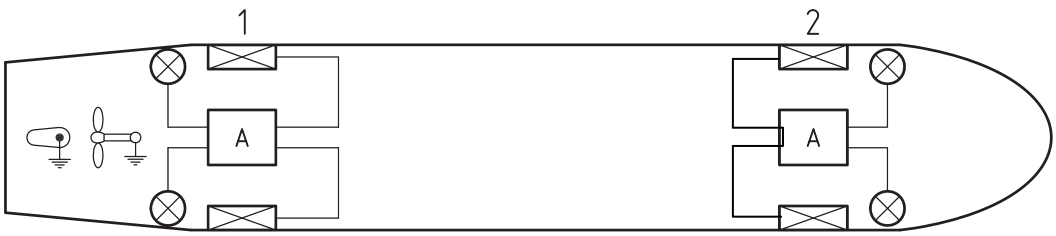
- The results of periodic maintenance inspection survey data including current (if possible) and protection potential measurements, equipment and the measuring technique in order to follow the changes of the protection potential status of the structure.

- An Operation and Maintenance Manual which shall detail the as-built system, inspection and testing procedures, and inspection and testing intervals. The data detailed above may in addition be incorporated into this volume.

Annex A
(informative)

Impressed current system for hulls of ships based on two cathodic protection zones

A schematic arrangement for an impressed current system for hulls of ships based on two cathodic protection zones is given in Figure A.1.



Key

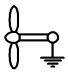
1 Aft (Stern) installation

2 Forward (Bow) installation

Protection current transformer rectifier with potential control


Impressed current anode (inert)


Permanent reference electrode


Propeller connection via shaft brush ring


Rudder grounding via cable

Figure A.1 — Typical arrangement for an impressed current system for hulls of ships based on two cathodic protection zones

Annex B
(informative)

Guidance on design current values for cathodic protection of hulls of ships

B.1 Typical design current densities for the cathodic protection of bare steel (J_b)

Typical design current densities for protecting bare steel are given in Table B.1.

Table B.1 — Typical design current densities for protecting bare steel

Situation	Typical cases	Typical Design Current Densities [mA/m^2]
Immersed Near static v ≤ 1 m/s	Boats, ships at anchor or berthed, ... without influence of tidal currents	100
Immersed Relative speed 1 < v < 3 m/s	Fishing boats ships or utility boats, harbour service ships, tugs, or openings at plating	250
Immersed Relative speed v ≥ 3 m/s	Moving vessels	≥ 500

Other bare metals such as cuprous alloys may be assimilated to bare steels.

To compensate for a less efficient electrical current distribution (due to a smaller number of higher current anodes), an impressed current cathodic protection system should be designed to be able to provide as a minimum 25 % more than the calculated maximum protection current demand.

Values as given in B.3 can be used where a global approach is considered.

B.2 Coating breakdown of conventional paint systems (f_c)

Initial coating breakdown factor: 1 to 2%.

Indicative annual depletion rates:

— 3% per year low durability coatings as EN ISO 12944-1 Im2

— 1,5% per year for medium durability coatings as EN ISO 12944-1 Im2

— 0,5% to 1% per year for high durability coatings as EN ISO 12944-1 Im2

For high-speed ships (speed above 25 knots) and ships in harsh or ice service annual depletion rate may be higher.

B.3 Typical current densities for global approach of the cathodic protection of coated ships (J_g)

Typical current densities for global approach of cathodic protection of coated hulls of ships are given in Table B.2.

Table B.2 — Typical current densities for global approach of cathodic protection of coated hulls

Docking periods (months)	Current densities (mA/m^2)
Up to 18	15 - 25
19 - 36	26 - 45
37 - 60	46 - 75

For special service vessels such as high speed vessels or ice breakers, higher current densities than those indicated above may be required.

Annex C
(informative)

Anode resistance, current and life duration formulae

C.1 Anode resistance formulae

C.1.1 General

The formulae given hereafter are generally used. Other formulae may be considered on the basis of documented experience.

C.1.2 For slender anodes mounted at least 0,3 m offset from the structure steel surface

Typically applicable to suspended anodes for laid up vessels.

if $L \geq 4r$

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

if $L < 4r$

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

Simplistically, for anodes mounted closer than 0,3 m offset from the steel surface but more than 0,15 m the resistance can be *assumed* to be R_a x 1,3. This simplification may be improved by mathematical modelling or direct field measurement.

C.1.3 Long flush mounted anodes on the structure steel surface where Length ≥ 4x Width

Typically applicable to long hull anodes; impressed current or galvanic.

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

C.1.4 Short flat plate mounted flush on the structure steel surface

Typically applicable to circular bow mounted impressed current anodes or short galvanic anodes.

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

where

R_a is the anodic resistance in ohms,

ρ is the environment resistivity in ohm metres,

L is the length of the anode in metres,

r is the radius of the anode (for other shapes than cylindrical, $r = C/2\pi$ 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.

For closely spaced arrays of anodes

Anodes in close proximity will affect the electrical field around adjacent anodes and reduce the current output from anodes, effectively the resistance of the individual anode in an array anode will be increased by the proximity to adjacent anodes.

Closely spaced anodes should be the subject of specific design assessment and their resistance may be determined by using alternate classical resistance to earth formulae, mathematical modelling or direct field measurement.

C.2 Calculation of the anode resistance at the end of life

The anode resistance will increase with time if consumption of the anode results in dimensional changes. It is necessary for the design to assess the current output capability of the anode at the end of life.

a) Calculation of end of life anode weight:

For all anode shapes:

$$W_{final} = W_{inital} \cdot (1 - u)$$

where

$\boldsymbol{W}$ is the net mass of anode alloy (excluding the steel core) in kilograms (kg)

$\boldsymbol{W_{initial}}$ is the Initial Value

$\boldsymbol{W_{final}}$ is the Final (or end of life) Value

$\boldsymbol{u}$ is the utilisation factor determined by the portion of anodic material consumed when the remaining anode material cannot deliver the current required (dimensionless). The shape of the anode and the design of the steel core within it will affect the utilisation factor, which may be in the range of 0,70 to 0,95.

b) Calculation of end of life anode dimensions:

1) For slender anodes

$$L_{final} = L_{initial} - (0.1 \cdot u \cdot L_{inital})$$

where

$\boldsymbol{L}$ is the length of the anode alloy in metre (m)

$\boldsymbol{L_{initial}}$ is the Initial Value

$\boldsymbol{L_{final}}$ is the Final (or end of life) Value

The depleted anode, with its steel core, is then assumed to be a cylinder with length L_{final} and its cross sectional area is calculated from the estimate of W_{final} above, the density of the anode alloy and the volume of the anode core within the final length of the anode.

$$X_{final} = \frac{W_{final}}{d_{anode} \cdot L_{final}} + X_{core}$$

$$r_{final} = \sqrt{\frac{X_{final}}{\pi}}$$

where

X_{final} is the final (or end of life) value cross sectional area of the anode (including the core) in square metres (m²)

X_{core} is the cross sectional area of the core in square metres (m²)

d_{anode} is the specific gravity of the anode alloy in kilogram per cubic metre (kg/m³)

r_{final} is the final (or end of life) anode radius in metres (m)

Final anode resistance is then determined according to relevant resistance formulae using values of r_{final} and L_{final}. as appropriate.

NOTE This formula will result in a calculated anode length greater than that indicated by the simpler design process in DnV RP B401; 2005); accordingly the calculated anode current output will be greater by this design process that that in DnV RP B 401.

2) For long flush mounted anodes

As for slender anodes but assuming that the final shape is a semi-cylinder. hence

$$r_{final} = \sqrt{\frac{2 \cdot X_{final}}{\pi}}$$

3) For short flush or bracelet anodes

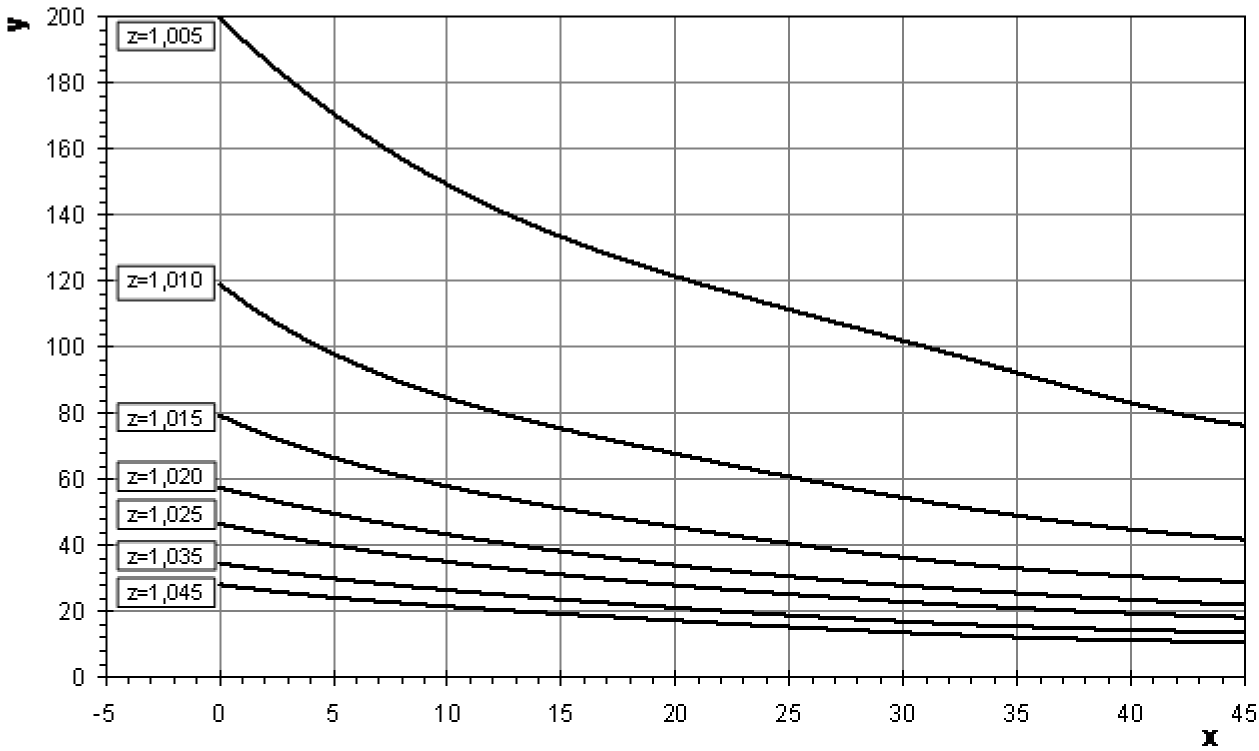
Assume that the resistance does not change from the Initial Value.

C.3 Electrolyte resistivity

Cathodic protection designs for port, harbour, coastal and flood protection installations should only be undertaken when the electrolyte resistivity relevant to the anode resistance calculation has been adequately measured and assessed. In particular in tidal areas where the water may become more brackish at low water and in areas where fresh water from rivers or surface water run off may significantly affect the resistivity, the water should be sampled and its resistivity determined. Sampling should be representative of all tidal conditions and all likely extents of fresh water contamination.

The resistivity of water changes significantly with temperature and should be assessed over the full range of normal temperature variations for the particular location. Temperature should be measured at every seawater resistivity determination and declared with the measured data to enable this assessment to be made:

The resistivity for different seawater densities (salinities) at different temperatures is shown in Figure C.1



Key

x temperature [°C]

y resistivity (ρ) [Ω cm]

z seawater density [kg/l]

Figure C.1 —Resistivity based on temperature and seawater density (salinity)

Electrolyte resistivity is of particular importance in the design of galvanic anode systems as use of inadequate resistivity data can have significant effect on the calculated anode resistance and then current output. The effect is less critical for impressed current anodes if the design provides for sufficient output voltage variation.

As indicative information only, the following resistivity values are typical:

For brackish water, the resistivity may fluctuate greatly (0,20 Ω m to 10 Ω m) depending on the salt content. As these values are so widely divergent it is evident that the actual values should always be measured as a preliminary to the design process.

— cold seawater : 0,30 Ω m to 0,35 Ω m (30 Ω cm to 35 Ω cm)

— warm seawater: 0,15 Ω m to 0,25 Ω m (15 Ω cm to 25 Ω cm)

— saline mud: 0,70 Ω m to 1,70 Ω m (70 Ω cm to 170 Ω cm)

— temperate brackish water 1,00 Ω m to 5,00 Ω m (100 Ω cm to 500 Ω cm)

— fresh river water 3,00 Ω m to 30,00 Ω m (200 Ω cm to 3 000 Ω cm)

C.4 Galvanic anode current output

The current output of a galvanic anode may be determined using Ohm's law.

$$I = \frac{\Delta U}{R}$$

where

I is the current output in amps,

ΔU is the driving voltage in volts,

R is the circuit resistance in ohms.

ΔU is generally taken as the potential difference between the polarised potential of the steel (5.2 ; -0,80 V with respect to Ag/AgCl/seawater) and the operating potential of the particular anode alloy in seawater (Typically -1,10 V to -1,05 V for aluminium based alloys, -1,05 V to -1,00 V for zinc based alloys and between -1,65 V and -1,45 V for the range of magnesium alloys all with respect to Ag/AgCl/seawater).

Therefore, subject to the characteristics of the particular anode for a structure being protected to -0,80 V with respect to Ag/AgCl/seawater without a risk of MIC with zinc alloy anodes, ΔU will be in the range 0,20 V to 0,25 V.

C.5 Anode life

The anode lifetime (T_{anode}) may be determined using the following formula:

$$T_{anode} = \frac{W_{anode} \cdot u}{E \cdot I_s}$$

where

T_{anode} is the effective lifetime of the anode in years,

W_{anode} is the net mass of anode alloy (excluding the steel core) in kg,

u is the utilisation factor determined by the portion of anodic material consumed when the remaining anode material cannot deliver the current required. The shape of the anode and the design of the steel core within it will affect the utilisation factor, which may be in the range of 0,7 to 0,95,

E is the consumption rate of the anode material in the environment considered, in kg/Ay (see EN 12496),

I_s is the average (mean) current output of the anode during the lifetime in amperes.

C.6 Minimum Net Weight Requirement

The minimum total net weight of the anode material required for a cathodic protection zone may be determined from:

$$W_{total} = \frac{I_{mean} \cdot T_{design} \cdot 8760}{Q \cdot u}$$

where

W_{total} is the minimum total net weight of galvanic anode material required, in kilogram (kg)

I_{mean} is the total maintenance current required for the structure, in amperes (A)

T_{design} is the design life (period between dry-docking) for the anode system in years (y)

u is the utilisation factor determined by the portion of anodic material consumed when the remaining anode material cannot deliver the current required (dimensionless). The shape of the anode and the design of the steel core within it will affect the utilisation factor, which may be in the range of 0,7 to 0,95

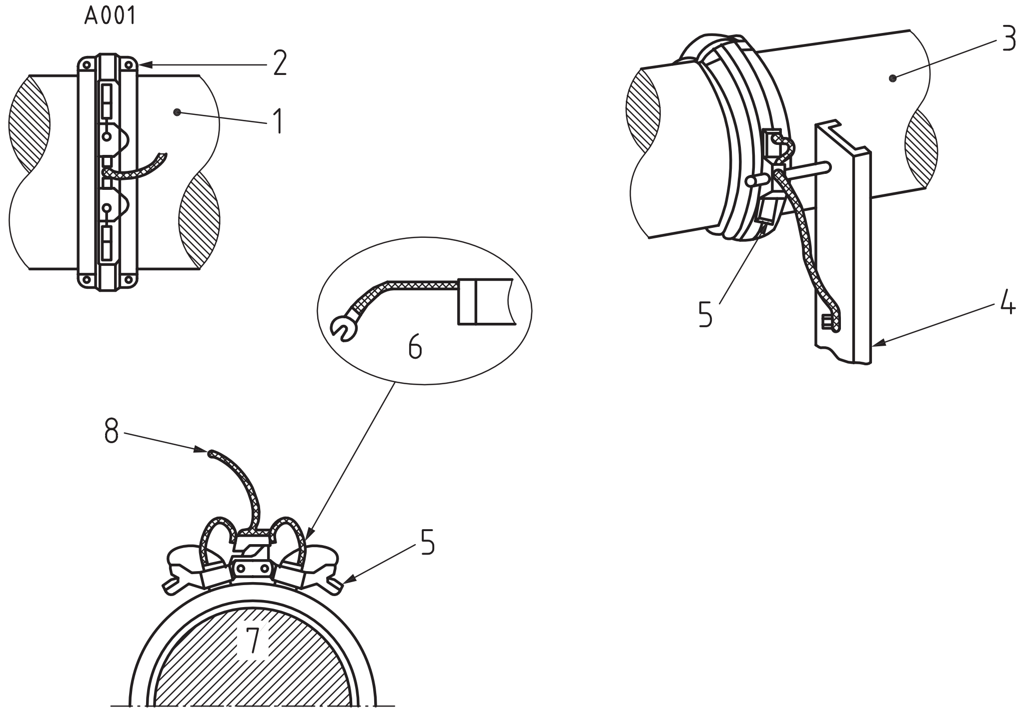
Q is the practical anode capacity for the anode material in the environment considered, in ampere-hours per kilogram (Ah/kg) (see EN 12496)

8760 is the number of hours in one year.

Annex D
(informative)

Electrical bonding systems

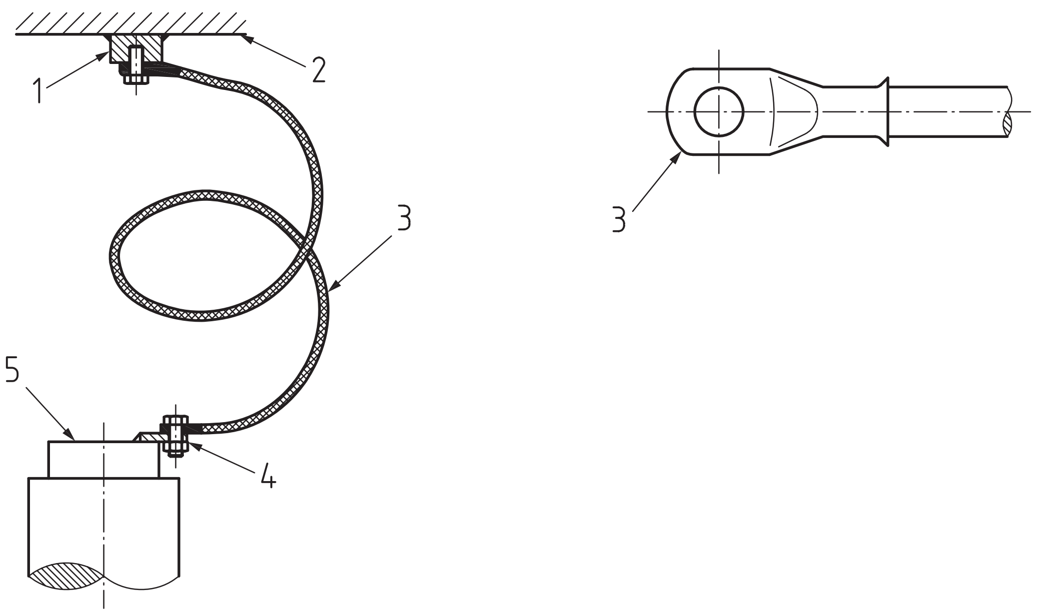
Examples of arrangements for achieving electrical bonding with the hull are illustrated in Figures D.1 (for shaft) and D.2 (for rudder).



Key

1 Shaft
2 Slip-ring halves adjusted to the shaft diameter
3 Propeller shaft
4 Bracket welded to the hull
5 Brush-holder with an electrical connection to the hull
6 Carbon brush minimum number = 2
7 Propeller shaft
8 Ground cable

Figure D.1 —Propeller shaft



Key

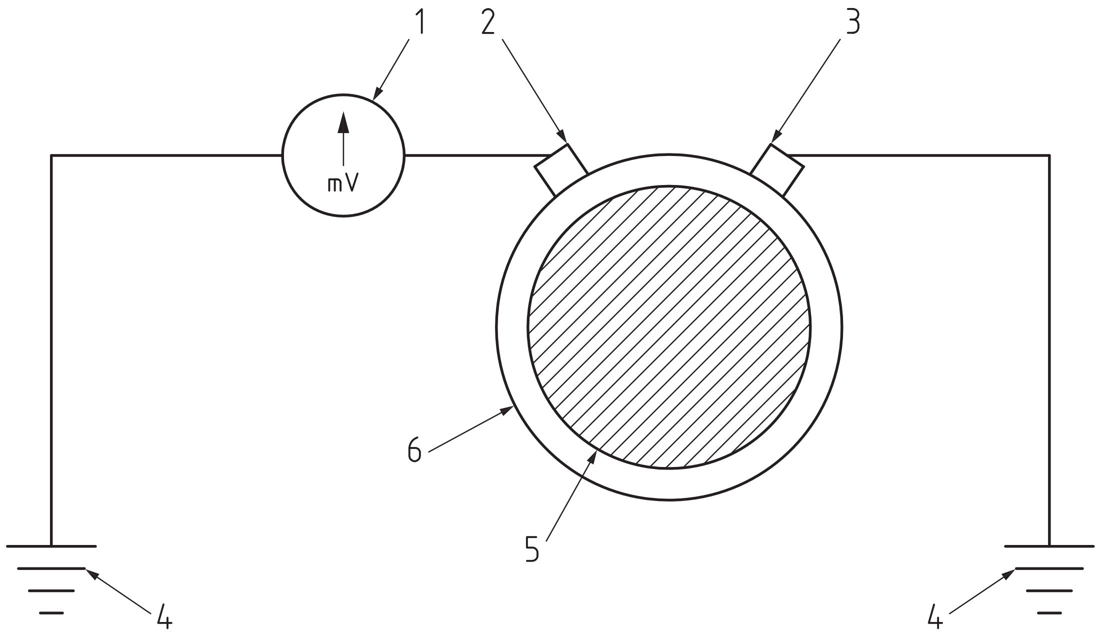
1 Socket for Bolt, brazed or welded
2 Hull internal
3 Ground cable and lug
4 Cable connected to brazed or welded lug on rudder stock
5 Rudder stock

Figure D.2 — Rudder

Annex E
(informative)

Monitoring of electrical bonding of a ship's propeller

A typical and optional arrangement useful for monitoring the quality of bonding between a the shaft of a propeller and the hull is represented by Figure E.1. A measurement of 0 mV between shaft and hull indicates optimum electrical continuity bonding. Except if otherwise specified, a maximum value of 50 mV is acceptable.



Key

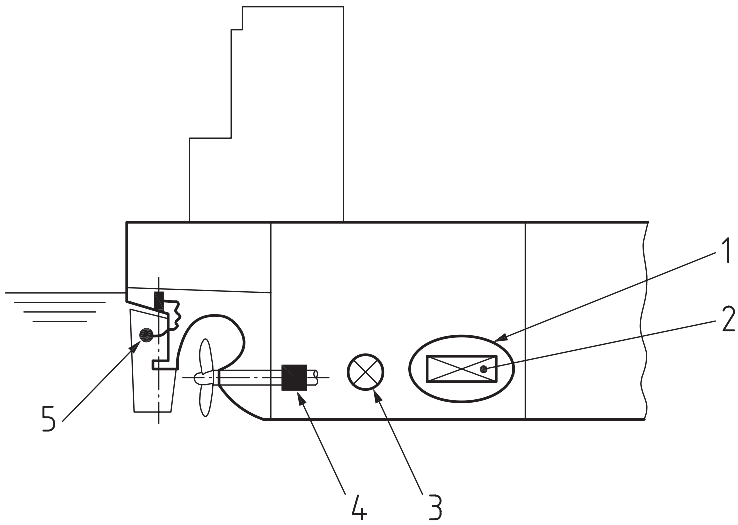
1 Centre zero mV analogue meter or DVM
2 Monitoring brush(es)
3 Bonding brush(es)
4 Cable connections to hull structure
5 Propeller shaft
6 Slip-ring

Figure E.1 — Typical arrangement for monitoring electrical bonding between shaft and hull

Annex F
(informative)

Impressed current system for ships based on an aft (stern) system only

A schematic arrangement for an impressed current system for hulls of ships based on an aft (stern) system only is given in Figure F.1.



Key

1 Dielectric shield
2 Inert anode
3 Reference electrode
4 Propelled shaft brush ring (As Figure D 1)
5 Rudder grounding (As Figure D 2)

Figure F.1 —Typical arrangement for an impressed current system for ships based on an aft (stern) system only

Annex G
(informative)

Location of galvanic anodes in the stern area

Typical locations of galvanic anodes are represented by black ovaloids in Figure G.1. Anodes should not be placed in the grey area shown. Recommended dimensions of the grey area are given in Figure G.2.

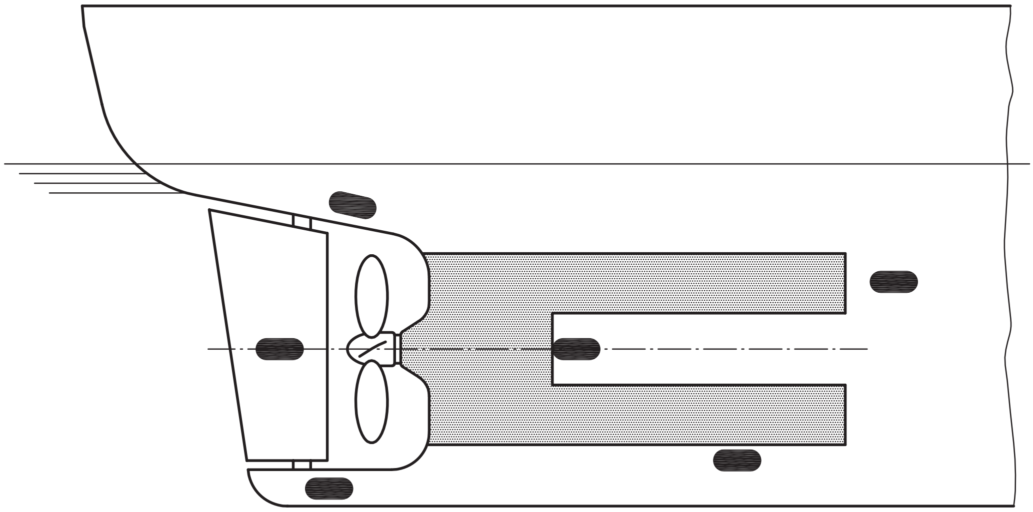


Figure G.1 — Arrangement of galvanic anodes in vicinity of propeller

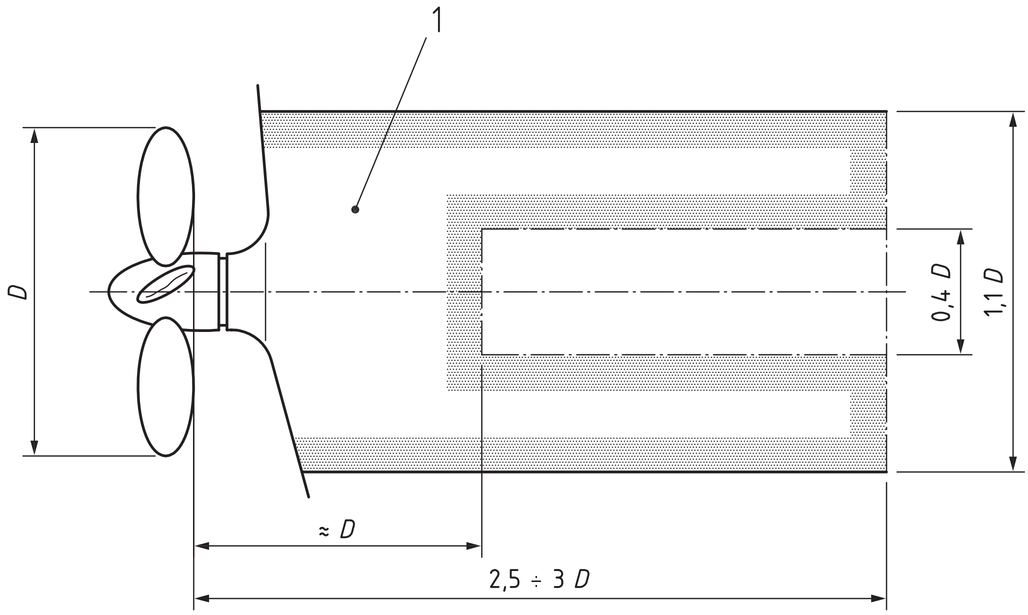


Figure G.2 — Dimensions of the grey area (1) not recommended for location of anodes

Annex H
(informative)

Electrochemical characteristics of impressed current anodes

Typical electrochemical characteristics of anodes used for impressed current systems of hulls of ships are given in Table H.1.

Table H.1 — Typical electrochemical characteristics of impressed current anodes

Anode materials	Consumption rate ($g.A^{-1}.y^{-1}$)	Maximum current density ($A.m^{-2}$)	Maximum voltage between anode material and electrolyte (V)
Platinised titanium	0,004 – 0,012[a]	500 - 3 000	8[b]
Platinised niobium	0,004 – 0,012[a]	500 - 3 000	50
Platinised tantalum	0,004 – 0,012[a]	500 - 3 000	100
Mixed Metal Oxide (MMO) on titanium substrate	0,000 5 - 0,001	400 – 1 000 [c]	8 [b]
Lead silver [d]	25 - 100	250 - 300	24

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. A magnitude lower than 100 mV (RMS) and a frequency not lower than 100 Hz are recommended.*

b *In seawater, the oxide film on titanium may break down if the anode potential exceeds 8V with respect to Ag/AgCl/seawater electrode. Higher voltages may be used with fully platinised or MMO coated anodes or in less saline environments.*

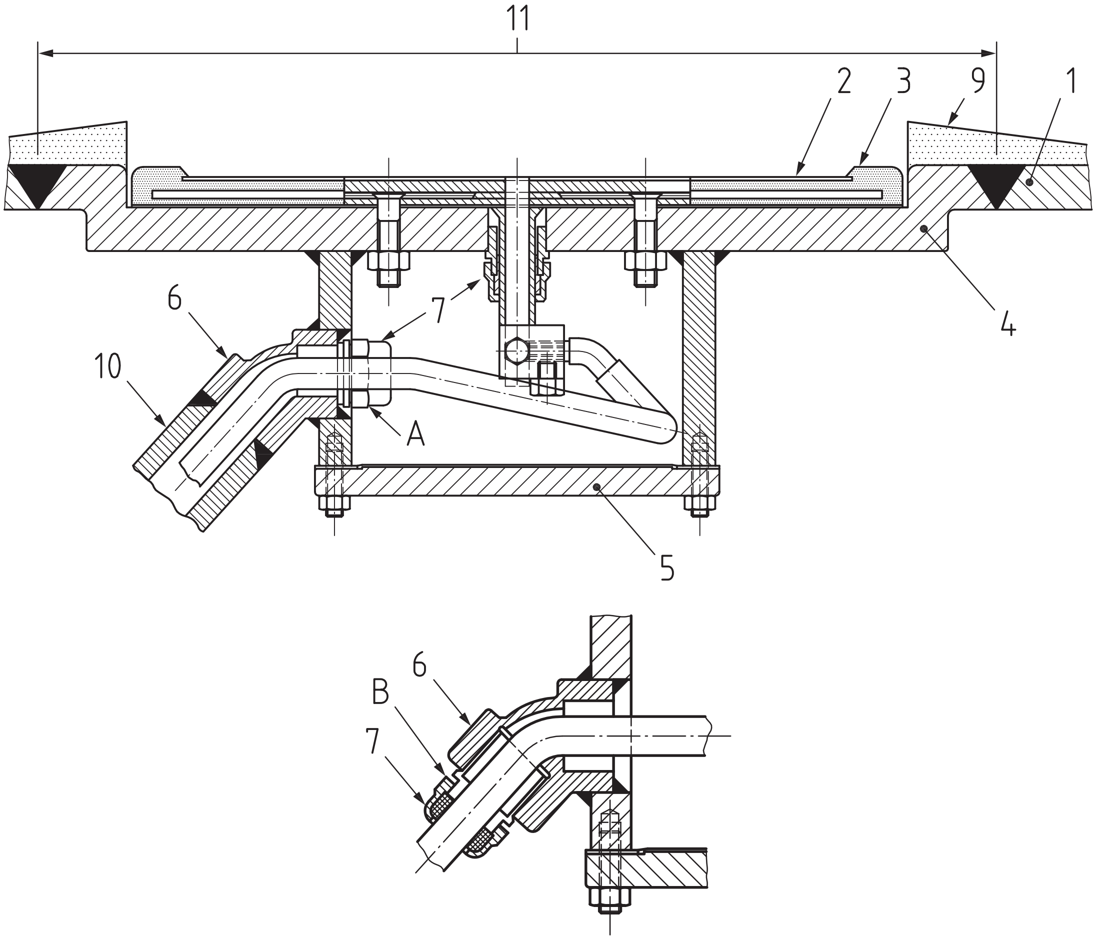
c *In cold seawater the maximum anode current density of Mixed Metal Oxide on titanium substrate anodes should be limited to 100 $A.m^{-2}$ between 0 and 5 °C and 300 $A.m^{-2}$ between 5°C and 10°C.*

d *PbO_2 film needs to be formed and maintained by a sufficient anodic current density (typically 100 $A.m^{-2}$ and 40 $A.m^{-2}$ respectively, in aerated seawater). The use of platinum pins in the lead/silver alloy may reduce these minimum values (typically to 50 $A.m^{-2}$ and 20 $A.m^{-2}$ respectively).*

Annex I
(informative)

Cofferdam arrangements

Typical examples of cofferdam arrangements are illustrated in Figures I.1 (for anode) and I.2 (for reference electrode).



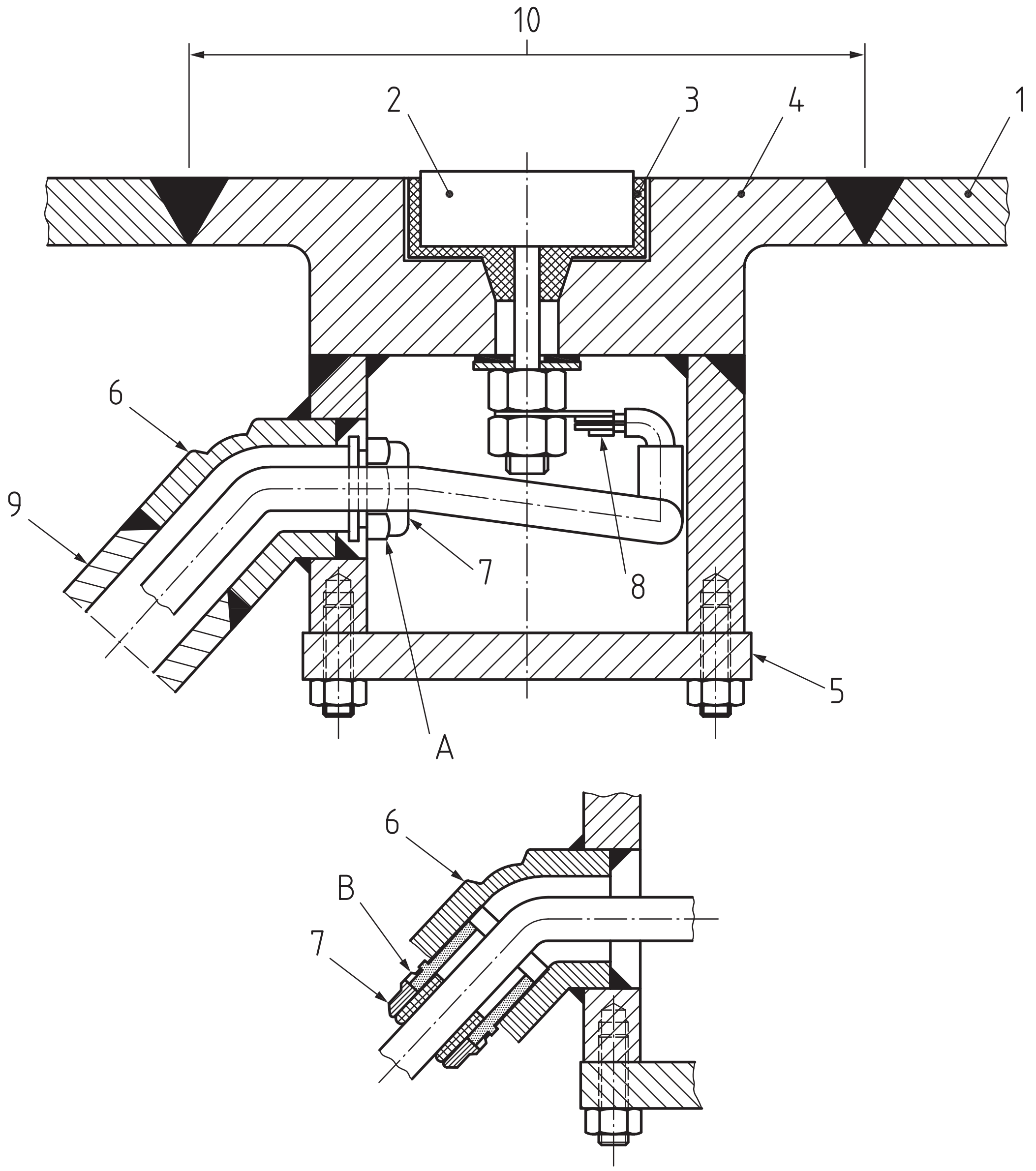
Key

1	Hull plate	2	Coated TI anode
3	Anode plastic body	4	Hull insert and Cofferdam
5	Cofferdam cover	6	Cable conduit elbow
7	Cable gland	8	Electrical clip
9	Anode shield	10	Cable tube in ballast tanks
11	Opening in shell plate		

NOTE 1 For installation in ballast tanks, the gland (N° 7) is mounted inside the cofferdam and details are as shown in upper diagram

NOTE 2 For installation in void space, the gland (N° 7) is mounted outside the cofferdam.

Figure I.1 — Typical recessed anode with cofferdam



Key

1 Hull plate

2 Reference electrode

3 Reference electrode plastic body

4 Hull insert and cofferdam

5 Cofferdam cover

6 Cable conduit elbow

7 Cable Gland

8 Electrical clip

9 Cable tube in ballast tanks

10 Opening in shell plate

NOTE 1 For installation in ballast tanks, the gland (N° 7) is mounted inside the cofferdam and details are as shown in upper diagram

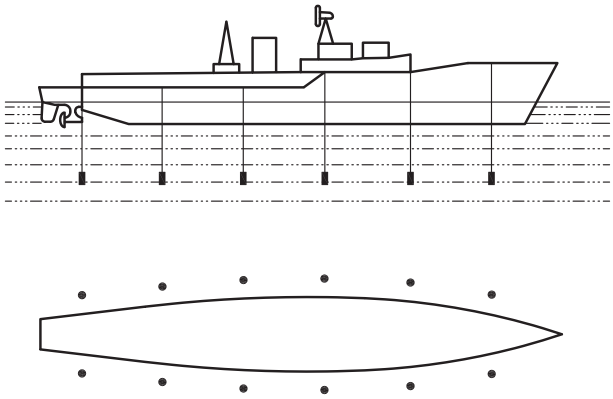
NOTE 2 For installation in void space, the gland (N° 7) is mounted outside the cofferdam

Figure I.2 —Typical reference electrode mountings with cofferdam arrangement

Annex J
(informative)

Cathodic protection of a moored ship using suspended galvanic anodes

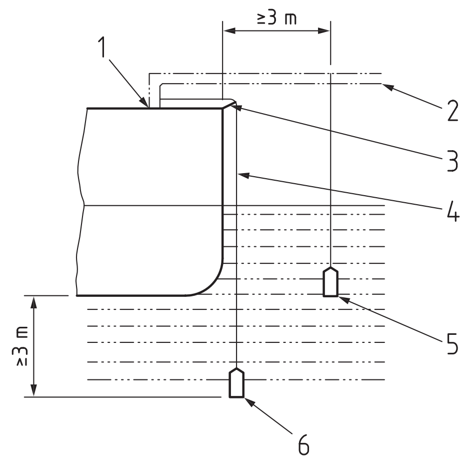
A typical system of suspended galvanic anodes used for protecting a moored ship is represented by Figures J.1 and J.2.



Key

1 Galvanic anodes at regular intervals around the ship

Figure J.1 — Location of suspended galvanic anodes for protecting a moored ship



Key

1 Good metallic contact to ships structure

2 Outrigger

3 Short spar

4 Electric cable

5 Alternative position of anode when there is less than 3 m of water below the keel

6 Galvanic anode

Figure J.2 — Location of suspended galvanic anodes for protecting a moored ship

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