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# Ships and marine technology — Cathodic protection of ships

*Navires et technologie maritime — Protection cathodique des navires*



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# Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by ISO/TC 8 *Ships and marine technology*, SC 8, *Ship design*.



# Introduction

Cathodic protection is applied to ships to protect the immersed sections of the vessel from corrosion. This includes the external hull surface and the internal surfaces of tanks containing seawater, e.g. ballast tanks.

Cathodic protection, often in conjunction with coatings, can be applied by impressed current, galvanic anode techniques or a combination of both.

Cathodic protection works by applying direct current to the immersed surface to change the steel-to-electrolyte potential to values where the rate of corrosion is considered insignificant.

The General Principles of Cathodic Protection in Seawater are described in ISO 12473.

Hull penetrations and cofferdams necessary for cathodic protection generally require Classification Society approval.



# Ships and marine technology — Cathodic protection of ships

## 1 Scope

This document specifies protection criteria, and makes recommendations for design and specifications for both impressed current and galvanic anode cathodic protection systems for ships. Cathodic protection of external hull and ballast tanks are included.

This document is applicable to the immersed sections of hulls and tanks containing seawater for ships, boats, and other self-propelled floating vessels. It includes fixtures generally encountered on ship hulls such as:

— rudders;

— propellers;

— shafts;

— stabilizers;

— thrusters;

— sea chests;

— water intakes (up to the first valve).

It does not cover protection of floating structures that are not self-propelled.

This document is applicable to the cathodic protection of ship hulls fabricated principally from carbon manganese or low-alloy steels including fixtures of other ferrous or non-ferrous alloys such as stainless steels and copper alloys, etc.

This document is applicable to both coated and bare hulls and tanks; most hulls and tank internals are coated.

This document is not applicable to the cathodic protection of hulls principally made of other materials such as aluminium alloys, stainless steels or concrete.

This document is applicable to the hull and fixtures in seawater and all waters which could be encountered during a ship's world-wide deployment.



## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 9606-1, *Qualification testing of welders — Fusion welding — Part 1: Steels*

ISO 12944-1, *Paints and varnishes — Corrosion protection of steel structures by protective paint systems — Part 1: General introduction*

ISO 12944-2, *Paints and varnishes — Corrosion protection of steel structures by protective paint systems — Part 2: Classification of environments*

ISO 15607, *Specification and qualification of welding procedures for metallic materials — General rules*

ISO 15609-1, *Specification and qualification of welding procedures for metallic materials — Welding procedure specification — Part 1: Arc welding*

ASTM B418, *Type 1 Standard specification for cast and wrought galvanic zinc anodes*

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

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

IMCA D045, *Code of Practice for Safe Use of Electricity Underwater*

## 3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

**3.1**
**system life**
design life of the cathodic protection system

**3.2**
**anode design life**
stated period for which the anode is required to be fully functional

**3.3**
**immersed zone**
zone located below the water line at draught corresponding to normal working conditions

**3.4**
**underwater hull**
immersed surface area of the hull at any given time

Note 1 to entry: Used to calculate current demand.

**3.5**
**boot topping**
section of the hull between light and fully loaded conditions

Note 1 to entry: Boot topping may be intermittently an immersed part of the structure which can be considered independently with respect to the cathodic protection design. A single zone can comprise a variety of components with differing design parameters.

**3.7**
**submerged zone**
zone including the immersed zone and the boot topping

**3.8**
**driving voltage**
difference between the steel-to-electrolyte potential and the sacrificial anode-to-electrolyte potential when the cathodic protection is operating

**3.9**
**closed circuit potential**
potential measured at a galvanic anode when a current is flowing between the anode and the surface being protected



**3.10**
**light ballast draught**
draught when the ship is in light ballast conditions

## 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 relevant level of competence for the tasks to be undertaken. This competence shall be independently assessed and documented. On-board routine measurements can be performed by non-specialists but the results interpreted by a cathodic protection specialist.

NOTE ISO 15257 and the NACE training and Certification Programme constitute suitable methods of assessing and certifying competence of cathodic protection specialists.



## 5 Design basis

### 5.1 General

**5.1.1** The objective of a cathodic protection system is to deliver sufficient current to protect each part of the structure and fixtures 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. Electrolytic anti-fouling systems cannot be assumed to provide cathodic protection to the sea chest and internal pipework. The impact of these systems on the overall cathodic protection design and control shall not be neglected. The designer shall consider the location of anti-fouling system anodes, current outputs, current attenuation, structure isolation (if any), local sacrificial anodes and current exchange across any hull grating in the overall cathodic protection design.

**5.1.2** Potentials should be as uniform as possible over the whole submerged surface. This objective is best achieved by adequate distribution of the protective current over the structure during the vessel's normal operating service conditions. This can be difficult to achieve in some areas of the structure (e.g. water intakes, thrusters, and sea chests) where specific provisions can be required.

**5.1.3** Cathodic protection for a ship is generally combined with a protective coating system. Although some fixtures, (e.g. propellers), are not usually coated.

**5.1.4** The cathodic protection system should be designed to mitigate galvanic coupling. The minimum protection potentials (most positive potential) listed in Table 1 shall be achieved on all steel surfaces adjacent to more noble materials.

**5.1.5** Cathodic protection within sea chests can adversely affect, by stray current interaction, box coolers in sea chests if the box coolers are electrically isolated from the sea chest. Box coolers are often manufactured from copper nickel alloy tubes. The possibility of interaction shall be considered when designing the cathodic protection requirements for the sea chest. These considerations should include methods of controlling corrosion on steel surfaces shielded by the cooler, whether the cooler is electrically isolated or not. The designer should also resolve the adequacy of any cooler manufacturer installed anodes. These may not last the intended service interval. The principles of concern for sea chest coolers shall be extended to copper-nickel keel coolers that are similarly installed.

Electrochemical anti-fouling systems are often used within sea chests to prevent the 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.

**5.1.6** The cathodic protection system shall be designed either for the life of the ship or on the basis of proposed dry-docking or maintenance intervals. The design life should be agreed between the cathodic protection system designer and the ship operator/owner.

NOTE Galvanic anodes can be sized for short periods such as dry-docking intervals. Impressed current materials can last longer, but not necessarily for the whole of the working life of the vessel, without replacement.

**5.1.7** Design, installation, energizing, commissioning, and long-term operation of all the elements of the cathodic protection system shall be fully documented.

**5.1.8** Every element of the work shall be undertaken in accordance with an approved, fully documented, quality plan.

**5.1.9** Each stage of the design shall be verified and the checking shall be documented.

**5.1.10** ISO 9001 is a suitable Quality Management Systems Standard that can be used.

## 5.2 Cathodic protection criteria

**5.2.1** The accepted criterion for the protection of bare steel in aerated seawater is a protection potential more negative than:

— −0,80 V measured with respect to a Ag/AgCl seawater reference electrode;

— +0,23 V measured with respect to a pure zinc electrode;

— +0,25 V measured with respect to a zinc electrode (made with alloy ASTM B418 Type 1 or US MIL-A-18 001K).

These three values are approximately equivalent.

**5.2.2** While Ag/AgCl/Seawater reference electrodes can be used on sea-going vessels, the use of zinc reference electrodes is an acceptable alternative. Zinc reference electrodes are considered sufficiently accurate and reliable. (See ISO 12473) (See 6.3.4)

**5.2.3** To avoid coating cathodic disbondment a negative limit of −1,1 V with respect to Ag/AgCl/Seawater reference electrode is recommended for hull coatings. Areas around dielectric shields and dielectric shields themselves shall be separately qualified to a maximum allowable limit. This limit can be varied provided that technical justification is provided.

**5.2.4** Where there is a possibility of hydrogen embrittlement of steels, or other metals, which may be adversely affected by cathodic protection at excessively negative values, a less negative potential limit shall be adopted (See Table 1). If there is insufficient documentation 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 polarized potential.

**5.2.5** The potential criteria and limit potentials are “polarized” and are expressed without IR errors. IR errors are a consequence of cathodic protection current flowing in the resistive electrolyte and surface films on the protected structure and are generally considered insignificant in marine cathodic protection applications that use galvanic anodes.

**Table 1 — Cathodic protection limits for materials commonly encountered on ship hulls and fixtures**

| Material | Most positive potential<br>(V vs. Ag/AgCl/seawater) | Most negative potential<br>(V vs. Ag/AgCl/seawater) |
|---|---|---|
| Carbon-manganese and low-alloy steels with specified minimum yield stress (SMYS) equal or lower than 550 N/mm$^2$ | | |
| In aerobic environment | −0,80 | −1,10 |
| In anaerobic environment and/or steel temperature >60°C | −0,90 | −1,10 |
| High strength steels (SMYS higher than 550 MPa) | −0,80 | −0,83 to −0,95 (see NOTE 1) |
| Aluminium alloys<br>(Al Mg and Al Mg Si) | −0,80 (negative potential swing 0,10 V) (See NOTE 5) | −1,10 |
| Austenitic steels or nickel base alloys containing chromium and/or molybdenum (See NOTE 6) | | |
| — (PREN ≥ 40) | −0,30 | no limit if fully austenitic, if not see NOTE 3 |
| — (PREN < 40) | −0,50 (see NOTE 2) | no limit if fully austenitic, if not see NOTE 3 |
| Duplex or martensitic stainless steels | −0,50 (see NOTE 2) | see NOTE 3 |
| Copper alloys | | |
| without aluminium | −0,45 to −0,60 | no limit |
| with aluminium | −0,45 to −0,60 | −1,10 |
| Nickel - copper alloys | −0,50 | see NOTE 4 |

NOTE 1 The negative potential limit should be determined by testing of the high strength steel for specific metallurgical and mechanical conditions.

NOTE 2 For most applications these potentials are adequate for the protection of crevices although more positive potentials may be considered if documented.

NOTE 3 Depending on metallurgical structure, these alloys can be susceptible to Hydrogen Stress Cracking (HSC) and potentials that are too negative should be avoided.

NOTE 4 High strength nickel copper alloys can be subject to HSC and potentials that result in significant hydrogen evolution should be avoided.

NOTE 5 Natural potentials shall be pre-determined to at least ensure at least a 0,10 V negative potential swing.

NOTE 6 PREN is defined in ISO 12473:2014.



## 5.3 Design process

**5.3.1** The design of a cathodic protection system requires a comprehensive and systematic approach. The design activity can conveniently be broken down into different stages.

a) Divide the structure into cathodic protection zones. (Each zone to be considered separately.) (see 5.4.1).

b) Fully describe each fixture and component in each zone.

c) Establish the service conditions.

d) Determine the current demand for each zone.

e) Establish cathodic protection system requirements for each zone.

f) Ensure that there is reliable, low resistance, electrical continuity between all components within a cathodic protection zone.

g) Design a cathodic protection system for each zone.

h) Assess design for possible interaction between zones.

**5.3.2** The design of impressed current systems is based on the maximum current demand. The design of galvanic anode systems for coated steel is based on the mean current and the maximum (final) current demand.

## 5.4 Design considerations

Detailed cathodic protection design shall take the following into consideration:

— structure cathodic protection zones;

— component characteristics;

— service conditions.

### 5.4.1 Cathodic protection zones of ship hull (external)

**5.4.1.1** The submerged surfaces of a hull can be divided into different cathodic protection zones which are then considered independently, even if they are not electrically separated. Although considered independently there can be interference between zones. This is particularly evident in the case of ICCP systems. The designer shall locate reference electrodes in key areas to measure the interference. The operating manual shall provide guidance to an operator to discern likely effects of zonal interference on observed anode current output in each zone and how this variation may occur as a function of hull coating deterioration.

**5.4.1.2** The immersed hull can be divided into two main cathodic protection zones:

— forward (bow);

— aft (stern).

**5.4.1.3** This is illustrated by the drawing in Annex A.

**5.4.1.4** These zones are related to the higher protection current demand in the aft zone due to high water flow rates, turbulence and the presence of dissimilar metals due to the propeller(s) and rudder(s).

**5.4.1.5** It is possible that some components can constitute a cathodic protection zone of their own (e.g. openings of sea chests, thrusters, rudders etc.).

### 5.4.2 Internal cathodic protection zones

**5.4.2.1** Complex geometries can exist within ballast tanks, e.g. stiffeners and heating coils.

**5.4.2.2** Lower sections of tanks not fully drained within stiffeners can also constitute discrete cathodic protection zones to be considered.

See 5.5.4.2 for further guidance.



### 5.4.3 Component characteristics

Each component of a cathodic protection zone as mentioned above shall be fully detailed in the design. This shall include:

— material type;

— specific potential limit (if applicable);

— complexity of the structure;

— surface area;

— coating characteristics, including type, thickness, predicted lifetime, anticipated coating breakdown.

### 5.4.4 Service conditions

The design of the cathodic protection systems for each external zone shall be related to the anticipated service conditions. Service conditions for internal surfaces are discussed in 5.5.4.2. Conditions to be taken into consideration include design life, environmental effects, cavitation effects and vessel operating conditions.

a) Design life. Either the entire cathodic protection design life or the dry-docking intervals should be considered. It should be noted that the predicted dry-docking intervals may be arbitrarily extended due to operational requirements and, wherever possible, the design should take this into account.

b) Environmental effects. The characteristics of the seawater (e.g. resistivity, temperature) should be established. Particular attention is required for vessels anticipated to operate in ice conditions or estuarine (brackish) and freshwater conditions.

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

d) Condition of the vessel coating and existing cathodic protection system.

**5.4.4.1** For ballast tanks, the cargo and the ballast period (wet/dry alternating period) shall be considered. Moreover, the ballast water composition and treatment system and its effect on the cathodic protection of the ballast tank shall also be taken into consideration.

## 5.5 Current demand

### 5.5.1 General

**5.5.1.1** To achieve the protection criteria for the conditions described in 5.2 it is necessary to select the appropriate design current density for each component within a zone with respect to the environmental and service conditions.

**5.5.1.2** The current demand of each metal component of the structure is the result of the surface area multiplied by the current density for the anticipated current demand.

**5.5.1.3** The total current requirement can be established by calculation of:

a) component surface areas;

b) protection current density for each zone:

   1) select a current density for bare steel and estimate the coating breakdown;

2) apply a global approach and use a current density that is based on experience for the coating type and service conditions;

c) if b)1) is selected there are two types of current demand that shall be applied. These are the maximum current ($I_{max}$) (i.e. end of system life current requirements) and the mean system current demand ($I_{mean}$).

**5.5.1.4** Guidance for cathodic protection current density requirements are given in Annex B.

**5.5.1.5** Guidance for the calculation of the anode resistance is given in Annex C.

**5.5.1.6** A global approach is described in 5.5.3.

### 5.5.2 Design current density for bare steel

**5.5.2.1** The selection of design current densities can be based on experience gained from similar ships operating in similar environmental and service conditions or by specific tests and measurements.

**5.5.2.2** The protection current density of bare steels, and other bare metals, depends upon the kinetics of the electrochemical reactions. It varies according to:

— the type of material;

— potential of the material;

— metal surface condition;

— electrolyte dissolved oxygen content;

— flow rate (or speed);

— temperature.

NOTE The current density is dependent upon the natural potential of the metal and the desired potential of the metal, which in the case of CRA may not be the potential required to achieve protection of the CRA. Instead it may be the applied protection value which would generally be that of the least noble metal. Greater potential shift will result in a higher current density.

**5.5.2.3** The protection current density requirements for each particular environmental and service condition shall be determined. It is entirely possible that different current density requirements are necessary for different operating conditions, and the cathodic protection design shall take account of this.

### 5.5.3 Design current density for coated steel

**5.5.3.1** The cathodic protection system is generally associated with a coating system. The coating system will reduce the cathodic protection current density and improves the current distribution over the immersed surfaces.

**5.5.3.2** The reduction of current density from bare steel to coated steel can be in the region of 100:1, or even higher under some circumstances, depending on the quality of the coating system applied. The cathodic protection current density for coated steel will increase with time as the coating deteriorates or is damaged.

**5.5.3.3** An initial coating breakdown factor, relating mainly to mechanical damage or coating application deficiencies that occur during the fabrication, should be considered. A coating deterioration rate (i.e. an increase in the coating breakdown factor over time) should be selected to take into account the ageing of the coating and mechanical damage to the coating that can occur during the operational lifetime of the cathodic protection, or a period corresponding to the dry-docking interval.

**5.5.3.4** The coating breakdown values are directly related to the construction, coating type, coating application, and anticipated coating performance and service conditions for the ship.

**5.5.3.5** Guidelines for coating breakdown values are given in B.2.

**5.5.3.6** The design current density required for the protection of coated steel is calculated as the product of the current density for bare steel and the coating breakdown factor:

$$J_c = J_b \cdot f_c \quad (1)$$

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;

$f_c$ is 0 for a perfectly insulating coating;

$f_c$ is 1 for bare steel.



**5.5.3.7** Because the current demand can be different for each cathodic protection zone, the calculation should be applied for each component or zone.

**5.5.3.8** An alternative design philosophy (global approach) for the estimation of the protection current density for coated structures can be considered when values for design parameters are well known from 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 B.1. The design 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. Without the verification that the cathodic protection system has been satisfactory it is not sufficient to accept a design only on the basis that it has been applied previously.

### 5.5.4 Current demand

#### 5.5.4.1 Hull systems

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

— $I_{max}$ maximum current demand (amps);

— $I_{mean}$ mean current demand (amps).

**5.5.4.1.1** $I_{max}$ corresponds to the most severe working conditions such as dynamic loads, end of life coating breakdown factor and worst case environmental conditions.

**5.5.4.1.2** $I_{mean}$ is used to calculate the minimum mass of galvanic anode material for the design life of the anodes or to determine the characteristics of impressed current anodes necessary to maintain cathodic protection throughout their design life

**5.5.4.1.3** For each cathodic protection zone these two protection current demands can be determined by using the following formulae:

$$I_{e\ max} = S_e \cdot f_{c\ max} \cdot J_{bd} \qquad (2)$$

$$I_{e\ mean} = S_e \cdot f_{c\ mean} \cdot [t \cdot J_{bd} + (1 - t) \cdot J_{bs}] \qquad (3)$$

where

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

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

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

$f_{c\ max}$ is maximum coating breakdown factor for the design life;

$f_{c\ mean}$ is mean coating breakdown factor for the design life;

$J_{bd}$ is current density for bare metal in dynamic conditions (A.m$^{-2}$);

$J_{bs}$ is current density for bare metal in static conditions (A.m$^{-2}$);

$t$ is fraction of time associated to dynamic conditions;

$I_{max}$ is used for design and equipment sizing for impressed current systems, with additional capacity as necessary.

**5.5.4.1.4** For each cathodic protection zone both values of cathodic protection current demand are given by the sum of the respective elements (summed over all components):

— $I_{maxtotal} = \sum I_{max}$ (A);

— $I_{meantotal} = \sum I_{mean}$ (A).

**5.5.4.1.5** If a global approach is adopted, a unique current demand is considered for each cathodic protection zone and the total current demand is:

— $I = J_g \cdot S_e$ $(A)$

where $J_g$ is the global current density selected.

See 5.5.3.

### 5.5.4.2 Ballast tanks

**5.5.4.2.1** All the surface areas wetted with water shall be considered in the design of the cathodic protection systems. It is preferable to determine the surface areas from CAD-drawings.

**5.5.4.2.2** The maximum surface area ($S_{max}$) is used as a basis for calculating the maximum current demand and includes the area of the flats as well as the supporting structure of T-beams, baffles, piping, etc. In all cases, it includes the area either of the top of the tank or of the structure.

**5.5.4.2.3** For tanks with varying levels (e.g. ballast tanks) there are two additional factors to be considered. Firstly, the ullage factor ($U_f$), which defines the maximum proportion of the surface of the tank that will be wetted (fully immersed) and, secondly, the wetting factor ($k$), which determines for what proportion of the design life the surfaces will be wetted. These two factors will allow the maximum operational surface area ($S_{op}$) to be calculated and used for the determination of the current demand for tanks with varying levels. The operational surface area, therefore, is the maximum surface area ($S_{max}$) multiplied by an ullage factor ($U_f$) and a wetting factor ($k$).

$$S_{op} = S_{max} . U_f . k \tag{4}$$

And this value is then substituted for $S_e$ in the formulae given in 5.5.4.1.

## 5.6 Cathodic protection systems

**5.6.1** Two types of cathodic protection systems can be used:

— impressed current;

— galvanic anodes.

The choice of the most appropriate system depends on many factors as described in ISO 12473. For external hull protection a combination of both systems can be used (hybrid system). However, for safety reasons, magnesium galvanic anodes and impressed current systems shall not be used for the internal protection of ballast tanks and other closed spaces.

**5.6.2** For any cathodic protection system, the anode output current can be determined using Ohm's law:

$$I = \Delta U / R \tag{6}$$

where

$I$ is the current output in amps;

$\Delta U$ is the driving voltage, in volts;

$R$ is the circuit resistance, in ohms.

**5.6.3** The circuit resistance is normally assumed to be approximately equal to the galvanic anode to electrolyte resistance or impressed current anode resistance to electrolyte plus cable resistance, as the cathode (structure) resistance to the electrolyte is generally very small.

**5.6.4** 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 can be used, such as those given in Annex C, to calculate the anode resistance.

**5.6.5** If anodes are grouped close to each other such that mutual interference between anodes occurs this shall be considered when calculating the individual anode resistance.

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

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

**5.6.8** 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

**5.7.1** Cathodic protection is required for fixtures such as rudders, stabilizers, propellers, thrusters etc., therefore electrical bonding to the hull shall be provided, except when the fixtures 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 to prevent galvanic corrosion damage to the adjacent hull or increased wear rate of bearings due to galvanic couples.

**5.7.2** The electrical resistance of the bonding shall be sufficiently low to ensure adequate protection of the fixtures connected.

**5.7.3** The electrical continuity shall be permanently maintained.

**5.7.4** The propeller shaft shall be electrically bonded to the hull. This is normally achieved by means of slip rings and brushes (See Annex D). It is desirable to monitor the electrical bond between shaft and hull. Bond resistance can increase with time and can deteriorate and fail if brush contacts are defective. A suitable arrangement for monitoring bond resistance is shown in Annex E.

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

### 5.8 Fitting out period

Precautions should be considered at the design stage to ensure cathodic protection during the fitting out period (see Clause 9).



## 6 Impressed current system

### 6.1 Objectives

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

**6.1.2** The electrical current output delivered by the d.c. power source (often a transformer-rectifier) is controlled during the lifetime of the cathodic protection system to obtain and maintain a protection potential level over the entire ship's hull, incorporating all the cathodic protection zones.

### 6.2 Design considerations

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

- design basis;
- sizing of equipment;
- general arrangement of the equipment;
- location of hull mounted 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; and

— maintenance plan.

**6.2.2** Impressed current cathodic protection systems for ships can include one or more sources of d.c. supply (e.g. transformer-rectifier) along with multiple anodes and reference electrodes.

**6.2.3** d.c. sources with automatic potential control are generally used because the environmental conditions, the structure configuration, and service conditions can cause large and frequent variations of the current demand necessary to maintain polarization (see 6.3.4).

**6.2.4** Each cathodic protection zone shall be protected by a dedicated system.

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

**6.2.6** The anodes shall be mounted on a dielectric shield to prevent localized over-polarization, coating damage, and improve the electrical current distribution to the cathode (see 6.3.3).

**6.2.7** The maximum protection current demand for a cathodic protection zone ($I_{max}$) should be calculated using formulae given in 5.5.4.1, based on the most severe service conditions as stipulated in that sub-clause.

**6.2.8** 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, as a minimum, 25 % more than the calculated maximum protection current demand.

**6.2.9** An overview of the different equipment concerned is given in Figure 1.

**6.2.10** The principal components of the impressed current system are:

— power source;

— monitoring and control systems;

— anodes;

— dielectric shields;

— reference electrodes;

— cables, connections;

— cofferdams;

— bonding and grounding systems.

## 6.3 Equipment considerations

### 6.3.1 Power source, monitoring and control systems

**6.3.1.1** All power source, monitoring and control systems shall be housed in control cubicles that are rated (IP rating) for the worst case environmental conditions. The cubicle shall be designed and mounted to ensure the effects of vibrations on the internal components do not affect the functionality of the equipment.

**6.3.1.2** The equipment shall be equipped with an input isolator.

**6.3.1.3** d.c. power requirements are most commonly met by the use of transformer-rectifiers operating from the ship's power. Transformer-rectifiers with automatic potential control are used to meet varying current demands caused by changes in the environmental conditions.

**6.3.1.4** The transformer rectifier delivers the protective current to the anodes and as a minimum shall be equipped with the following monitoring instrumentation and control facilities:

— a voltmeter for the measurement of the d.c. output voltage;

— an ammeter for the measurement of the anode d.c. current 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;

— provision for the external check of output voltages and currents using a calibrated instrument.

**6.3.1.5** An hours-run meter can be installed for recording the operational periods of the d.c. power source.

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

— over-polarization of the hull or appurtenance;

— under-polarization of the hull or appurtenance;

— over-current to anodes.

**6.3.1.7** 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.

**6.3.1.8** 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.

**6.3.1.9** The transformer-rectifier shall be able to deliver the maximum design current [plus at least 25 % extra capacity (6.2)] to the cathodic protection zone that it is intended to protect.

**6.3.1.10** The transformer-rectifier output voltage shall take into account the resistance of the electric circuit (cables, anodes), the back-emf and the recommended operating voltage of the anodes. The voltage at the anode shall not exceed the safety values given in IMCA D045 Code of Practice for Safe Use of Electricity Underwater.

**6.3.1.11** The AC ripple shall be limited to 100 mV RMS (root mean square) at a frequency of no less than 100 Hz (i.e. full wave rectification and smoothing are required for the anode power supply) in order to limit impact on the consumption rate of platinum coated anodes (see Annex H).

**6.3.1.12** The transformer-rectifier shall have a selectable potentiostatic control which automatically delivers variable electrical current in order that the steel to electrolyte potential measured by the reference electrode used for the control is maintained within the required protection limits. The transformer-rectifier units should also have the capability to operate in constant current/constant voltage control mode to facilitate commissioning and fault finding. However, in normal operation, transformer- rectifiers should only operate in potentiostatic mode.

**6.3.1.13** 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.

**6.3.1.14** A facility to limit the output current to each anode to a maximum value shall be provided. This facility shall not be able to fail in such a way that full current output is applied to the anode(s).

### 6.3.2 Anodes

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

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

**6.3.2.3** The anode element shall be mounted in a non-conductive holder in a manner that recesses the anode element and minimizes the possibility of mechanical damage and drag. The anode element shall be sealed into the holder to prevent ingress of water to the back face of the element. The holder shall be of a material suitable for seawater service and capable of maintaining electrical isolation of the anode from the hull under operating conditions.

**6.3.2.4** 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.

**6.3.2.5** Lead/silver alloy (semi-inert) anodes can 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. These anodes shall only be used where they are environmentally acceptable.

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

**6.3.2.7** Generally, only a few anodes are required for high current outputs. The loss of an anode, therefore, can significantly reduce the performance of the system.

**6.3.2.8** The anode assembly and its attachment shall be designed to have a high resistance to mechanical damage. Special considerations are required for ice-going vessels.

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

**6.3.2.10** The anode assembly shall be designed to have a low profile to minimize drag when the vessel is underway.

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

**6.3.2.12** 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 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 at the through-hull penetration (see 6.3.6).

**6.3.2.13** The number, dimensions and location of anodes shall be determined in order to deliver the maximum protection current demand and to achieve the cathodic protection criteria for the entire cathodic protection zone protected by that cathodic protection system.

### 6.3.3 Dielectric shields

**6.3.3.1** Each impressed current anode shall be mounted on a dielectric shield to ensure that the anode/cathode separation is sufficient to eliminate the risk of over-polarization close to the anode. Calculations shall be carried out, and documented, to show that the potential at the edge of the dielectric shield (i.e. the anode/cathode separation) complies with the limits given in Table 1. Examples of equations that can be used are given in Annex K.

Designs limiting the potential at the edge of a dielectric shield to a value other than the limits within Table 1 shall be justified.

**6.3.3.2** Yard-applied additional coatings, fibreglass reinforced plastic, prefabricated plastic or elastomeric sheets can be used to effectively extend the dielectric shield. All dielectric coatings shall be compatible with the intended ship anti-corrosion and anti-fouling coating system.

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

**6.3.3.4** Pre-fabricated shields can be extended by the use of additional coatings compatible with the intended ship overall coating system.

### 6.3.4 Permanent reference and measurement electrodes

**6.3.4.1** Reference electrodes are used to measure the hull to seawater potential and are generally used to allow the control of the electrical current delivered by impressed current cathodic protection systems. Reference electrodes can also be used to monitor hull potentials at strategic locations. Electrodes are generally zinc or silver/silver chloride/seawater (see ISO 12473). Zinc electrodes are more robust whereas silver/silver chloride/seawater reference electrodes are more accurate.

**6.3.4.2** Precautions shall be taken to avoid any direct electrical contact between the electrodes and the hull plates. Similarly, precautions shall be taken to avoid 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 (see Figure I.2).

**6.3.4.3** Reference electrodes shall be installed at locations determined by calculation, or experience, to ensure the potential of the hull is maintained within the prescribed upper and lower potential limits.

**6.3.4.4** Reference electrodes shall be replaceable. See 6.3.6. 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. Zinc is generally used as a measuring or controlling electrode but its accuracy is generally in the range ±50 mV. See EN 12473.

### 6.3.5 Cables and terminations

**6.3.5.1** All connecting cables should be of mechanically and chemically robust construction and fitted with 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.

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



**6.3.5.3** Anode cables shall be clearly marked with a permanent cable marker, e.g. anode.

**6.3.5.4** Structure cables shall be clearly marked with a permanent cable marker, e.g. structure.

**6.3.5.5** Reference electrode cables shall be clearly marked with a permanent cable marker, e.g. ref1.

**6.3.5.6** The cable and termination insulation materials shall be resistant to their environmental conditions and satisfy classification requirements.

**6.3.5.7** When determining the cross-section of the cable conductor, it is necessary to take into account the mechanical strength as well as the voltage drop for the length of cable under consideration.

**6.3.5.8** The specified maximum current rating, including any de-rating factor, for a given size of cable conductor shall never be exceeded.

**6.3.5.9** For potential measurements, dedicated monitoring cables shall be used. Consideration should be given to these cables being screened to avoid any electrical or radio frequency electrical interference to the measured potential signals.

**6.3.5.10** Cables shall comply with IEC standards for ship wiring and Classification Society requirements. Cables for impressed current cathodic protection systems shall not pass through tanks intended for low flash-point products. Cables leading to cofferdams can be required to be enclosed in sealed steel conduit.

**6.3.5.11** Cables shall not be handled, installed or maintained beyond the recommended minimum bend radii and installations e.g. cofferdams and anode assemblies shall be designed accordingly.

### 6.3.6 Cofferdams

**6.3.6.1** All hull penetrations shall be made via integral cofferdams (see Annex I) whose structural design shall meet Classification Society requirements.

**6.3.6.2** Cofferdams should be constructed of materials which are metallurgically compatible with the hull material.



# 7 Galvanic anode systems

## 7.1 Objectives

**7.1.1** 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 design life of the system.

**7.1.2** For a galvanic anode system, current is provided by the galvanic action between the structure and the anodes (e.g. alloys of aluminium, zinc or magnesium) which has a potential that is more electro-negative than the structure to be protected.

**7.1.3** 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.

**7.1.4** Galvanic anode systems are applicable to both external hull protection and the protection of internal surfaces of tanks and other enclosed spaces.

## 7.2 Design considerations

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

**7.2.2** 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 installation procedures and detailed drawings;

f) cathodic protection potential acceptance criteria.

**7.2.3** The inner face of surface mounted galvanic anodes should be coated with a paint system suitable for a marine environment. Additional elastomeric linings may also be necessary to protect susceptible structure coatings from mechanical damage. Galvanic anodes should preferably be attached by continuous welding of their steel insert to the structure in such a manner that stresses are minimized 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 (doubler plates) which have been connected to the structure by continuous welding. An attachment to studs 'fired' into the structure is not permitted. Stud welding is permitted. Low electrical resistance contact shall be maintained throughout the operating life of the anodes.

**7.2.4** When low hydrodynamic resistance is required, shapes and methods of attachment of anodes should be optimized accordingly.



## 7.3 Anode materials

**7.3.1** Galvanic anodes are described in Annex L.

**7.3.2** The electrochemical properties of the anode material should be documented or determined by appropriate tests.

**7.3.3** The information required for design purposes includes:

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

— the practical electrical current capacity ($Ah.kg^{-1}$) or consumption rate ($kg.A^{-1}.a^{-1}$);

— the susceptibility to passivation;

— the susceptibility to intergranular corrosion;

— the total current requirements (for the zone);

— the design life of the anodes.

**7.3.4** Galvanic anodes for use on ships are usually made of zinc or aluminium based alloys. All anodes used on tanks or on the external hull shall be of the same alloy type. Any exceptions to this shall be technically justified and documented in the design documentation. Exceptions shall also be noted in maintenance documentation.

**7.3.5** Magnesium anodes are not recommended for use on ship hulls because their high operating potentials can lead to over-polarization (5.2) and possible coating disbondment. Provided that there is no risk of over-polarization they can be used for the provision of temporary cathodic protection of the external hull. Magnesium anodes shall not be used inside tanks and enclosed spaces.

NOTE Magnesium anodes have been used for descaling purposes in ballast tanks but this is carried out with adequate ventilation and for relatively short periods under close supervision.

## 7.4 Factors determining the anode current output and operating life

**7.4.1** The anode electrical current output depends on its dimensions, the resistivity of the surrounding water and the driving voltage. Anodic materials exhibit different specific consumption rates when operating in various environments. The current output from a galvanic anode will decrease as the anode is consumed and the dimensions decrease. Annex C gives guidance on the calculation of anode current output for anodes of various shapes and dimensions including end of life dimensions.

The anode weight required is determined by the design life of the anodes, the mean current demand over this design life and the electrochemical properties of the anode material as detailed in Annex C.

**7.4.2** The dimensions and number of galvanic anodes required for each cathodic protection zone shall be optimized to ensure that sufficient total initial weight of anode material is installed to last for the design life (Annex C) and that the current demand for each cathodic protection zone is satisfied by the number of anodes installed even when consumed to their design utilization and when any coatings have deteriorated such that the current demand is at its highest.

NOTE 1 There are limitations on the practical use of aluminium anodes in higher resistivity waters, e.g. brackish water of resistivity >2 ohm.m when zinc anodes can then be used.

NOTE 2 The electrochemical capacity of aluminium anode alloys is affected by operation at very low anode current density as might be encountered with anodes on steels with a high-quality coating.

**7.4.3** The dimensions and number of anodes should be optimized to:

— minimize the total weight of the galvanic anodes;

— provide a protective electrical current greater than or equal to the mean and maximum protection current demand required for the permanent protection of the ship during the life of the anodes;

— provide uniform cathodic protection current distribution.

**7.4.4** The commonly used net driving voltage between an anode made of a typical aluminium based alloy or zinc based alloy and a polarized or coated structure at its minimum cathodic protection level (−0,8 V with respect to Ag/AgCl/seawater) is between 0,15 V to 0,30 V.

**7.4.5** The anode weight to achieve the design life should be determined using the calculation procedure given in C.6.

**7.4.6** Under conditions of wet-dry cycling it is possible for an anode to passivate. Normal anode functionality may take some time to be restored when a previously dried out anode is re-immersed.

## 7.5 Location of anodes

### 7.5.1 External hull surfaces

**7.5.1.1** The galvanic anodes required for each protective zone shall be distributed to ensure that the steel surface is polarized within the recommended limits. Additional calculations can be performed using computer numerical modelling based on finite element or boundary element methods.

**7.5.1.2** 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:

— The stern area, including rudder and propellers, shall be regarded as a separate cathodic protection zone because of the higher current demand caused by additional water turbulence and galvanic metal couples. However, care is needed when locating anodes in this area since injudicious location can lead to cavitation effects. See Annex G.

— The remainder of the anodes shall be spaced along the length of the hull, preferably along suitable flow lines, to minimize drag. The anodes should be spaced evenly or in longitudinal groups. Anodes located in close transverse proximity can be subject to mutual interference which reduces their current output. They should not be attached to areas likely to sustain regular mechanical damage, e.g. in the way of the anchor chain or where wharf damage is probable. Areas likely to sustain more mechanical coating damage e.g. from anchor chain abrasion, such as the forward quarters, can require additional anodes. Where a bilge keel is fitted the anodes should be attached on either side.

**7.5.1.3** 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.

**7.5.1.4** Where anodes are to be attached to plating of fuel oil or oil cargo tanks or internally coated areas consideration shall be given to the use of doubler plates which have been continuously welded to the hull.

**7.5.1.5** 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.

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

Sacrificial anodes will not usually cause stray current interference even in a complex chest. Electrolytic anti-fouling anodes installed in the chest, however, can cause interference.

### 7.5.2 Internal surfaces

#### 7.5.2.1 Anode location in tanks

**7.5.2.1.1** For installation in tanks and structures which may not be completely drained, anodes shall be located at the lowest point possible.

**7.5.2.1.2** In ballast tanks, anodes shall be attached to stiffeners and not directly to shell plates. At the bottom of the tank, the anodes shall be located within sections enclosed by the webs of the stiffeners on the floor area to ensure that the anodes are always at lowest water levels.

**7.5.2.1.3** Except for small anodes installed at the lowest point of ballast tanks in locations which may not be completely drained, anodes should be fixed at each end and not at a single point.

**7.5.2.1.4** All anodes shall be attached in such a manner that they will remain securely fastened when in service. Galvanic anodes should preferably be attached to the structure by continuous welding of the anode steel insert. Welding shall not take place adjacent to stress raisers such as toes of fillet welds and changes in steel section. On stiffener flanges anode insert welds should be in line with the stiffener and located above the web centre line. On other steel sections, the weld should not be closer than 25 mm from the free edge.

**7.5.2.1.5** The welding of the anodes or of the supports shall be performed in accordance with the relevant requirements of ISO 15607 and ISO 15609-1 or any equivalent standard.



NOTE AWS D1.1/D1.1M constitutes an acceptable equivalent.

**7.5.2.1.6** Welds shall be performed by welders qualified according to ISO 9606-1.

NOTE AWS D1.1/D1.1M constitutes an acceptable equivalent.

**7.5.2.1.7** The steel insert of the galvanic anodes can be bolted to separate supports (brackets) connected to the stiffeners by continuous welding. Anodes can also be attached to flanged stiffeners by the use of bolted clamps of an approved design. In such cases the clamping bolts shall be fitted with additional locking nuts. Electrical continuity checks shall be performed and the resistance shall be such that the ohmic drop across any bolted connection is less than 10 % of the design driving voltage between anode and steel structure, and shall not be greater than 0,1 ohms.

**7.5.2.1.8** Other methods of anode attachment shall be pre-qualified.

**7.5.2.1.9** Magnesium anodes shall not be used inside ballast and other closed tanks where flammable gases might be produced. Aluminium anodes can be used with a restriction on the height at which they can be mounted in tanks on oil tankers with liquid cargo with flash point below 60 °C and in ballast tanks adjacent to oil cargo tanks.

**7.5.2.1.10** To mitigate ignition risk, aluminium alloy anodes, plus fixings, shall not be located at a height where the potential energy exceeds 275 J.

This is deemed to be at a height from the tank bottom, deck or intervening member surface determined by:

$$H < 28/W \quad (7)$$

where

$H$ is the height in meters;

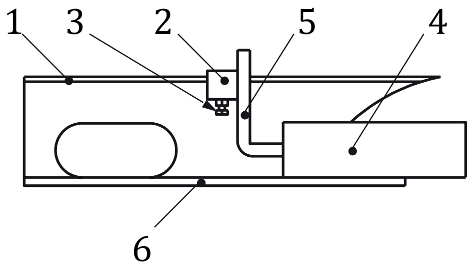
$W$ is the gross weight of the anode plus fixings, in kg.

**7.5.2.1.11** Aluminium anodes shall be located at positions where they are protected from directly falling objects.

**7.5.2.1.12** There is no height restriction for zinc anodes.

**7.5.2.1.13** Anodes shall be attached to stiffeners and not directly to shell plates.

**7.5.2.1.14** At the bottom of the tank the anodes shall be located within sections enclosed by the webs of the stiffeners on the floor area but not attached on the webs themselves. This will ensure that the anodes are always in seawater at lowest water levels. See Figure 1.




**Key**

1 bottom frame stiffener

2 U-clamp

3 securing and continuity screw

4 anode

5 anode steel bar insert to be welded to U-clamp

6 tank

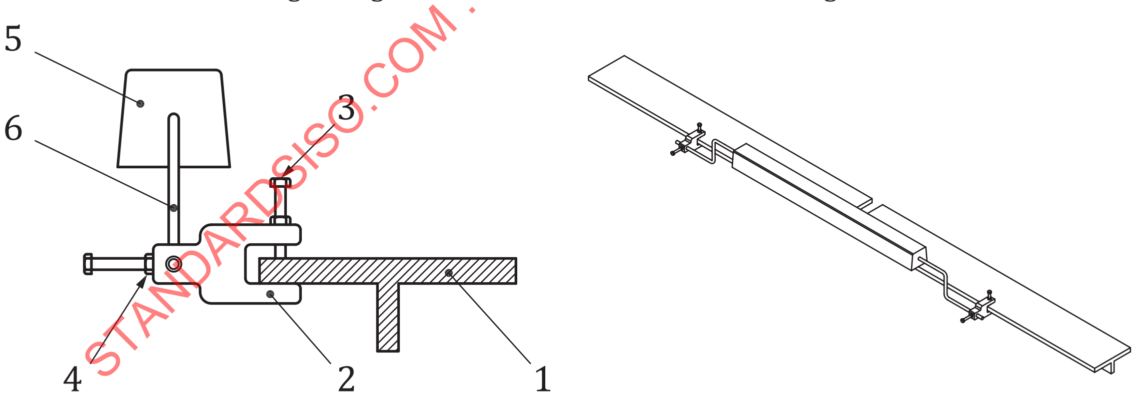
**Figure 1 — Example of attachment of a galvanic anode on a stiffener of a tank bottom**



**7.5.2.1.15** The remainder of the anodes shall be distributed over the tank bottom and wall areas in due consideration of the wetted area of the tank.

**7.5.2.1.16** Galvanic anodes should preferably be attached to the structure by continuous welding of the anode steel insert. Stresses should be minimized at the weld location.

**7.5.2.1.17** The steel insert of the galvanic anodes can be bolted to separate supports connected to the structure by continuous welding. Anodes can be attached to flanged stiffeners by the use of bolted clamps of an approved design (see Figure 2). In such cases the clamping bolts shall be fitted with additional locking nuts. A continuity check shall be performed and the resistance shall be such that the ohmic drop is less than 10 % of the driving voltage, and in no case result in a value higher than 0,1 ohms.




**Key**

1 structural stiffener

2 M-clamp

3 securing and continuity screw

4 security and continuity screw

5 anode

6 anode steel insert bar

**Figure 2 — Example of installation of a galvanic anode in a tank using clamps**

**7.5.2.1.18** Except for small anodes installed at the lowest point of ballast tanks in locations which may not be completely drained, anodes should be fixed at each end and not at a single point. Anodes should not be attached to separate members which are capable of relative movement. See DNV Rules for Classification of Ships Part 8, Chapter 1, section 6.

The welding of the anodes or of the supports shall be performed in accordance with the relevant requirements of ISO 15607 and ISO 15609-1 or any equivalent standard.

NOTE 1 AWS D1.1/D1.1M constitutes an acceptable equivalent.

Welds shall be performed by welders qualified according to ISO 9606-1.

NOTE 2 AWS D1.1/D1.1M constitutes an acceptable equivalent.

Alternative methods of anode attachment shall be pre-qualified.

The inner face of surface mounted galvanic anodes may be coated but are generally left bare.

**7.5.2.1.19** Ballast tanks containing seawater where service conditions are likely to involve the presence of explosive gas mixtures (i.e. adjacent to oil storage tanks), the selection and location of galvanic anodes are governed by safety regulations.

**7.5.2.1.20** Classification Society rules prohibit the use of magnesium anodes and restrict the height at which aluminium anodes can be mounted in tanks on oil tankers with liquid cargo with flash point below 60 °C and in ballast tanks adjacent to oil cargo tanks.



# 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 and installation in terms of the prescribed cathodic protection potential limits;

— the cathodic protection system for the ship's hull, ballast tanks, and fixtures continues to perform in accordance with the design;

— levels of interference and interaction are within acceptable limits prescribed in the design; and

— all measurements shall be made by competent persons (see Clause 4).

## 8.2 Measurement procedures

**8.2.1** The metal/seawater potential shall be measured using a high impedance (10 MΩ minimum) voltmeter connected to a reference electrode (also known as a measurement electrode when used exclusively for measurement). Measurement electrodes shall be located as close as possible to the steel/seawater interface being measured.

**8.2.2** When permanent measurement electrodes are installed they should be at locations judged to be representative of the most negative and the most positive potentials (see also 6.3.4) on the external hull surface. Additional reference electrodes shall be installed in areas where the potential of the structure is more likely to change beyond the set limits.

**8.2.3** In the case of impressed current systems, reference electrodes shall be fitted to the structure at suitable locations to automatically control the output of the anodes and ensure critical areas are polarized to within the set limits.

**8.2.4** 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 can become polarized and give false indications.

**8.2.5** The use of portable coupons and electrical resistance probes can be considered for commissioning to allow readings to be made in areas where there is no permanent reference electrode installation. They can be particularly useful when establishing the effectiveness of the dielectric shields.

## 8.3 Commissioning: Galvanic systems

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

**8.3.2** Ballast tank system potential measurements can only be made using permanently installed reference electrodes.

**8.3.3** 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 commissioned in brackish water the cathodic protection surveying for commissioning should be undertaken as soon as possible after the vessel is in undiluted seawater.

**8.3.4** A repeat survey as above should be undertaken one 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

**8.4.1.1** 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 marine life damage.

**8.4.1.2** 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 d.c. supply output shall be confirmed.

**8.4.1.3** All the installed anodes and reference electrodes shall be visually inspected to confirm that the installation is in accordance with the detailed design documentation and that the anodes and electrodes have not been coated.

**8.4.1.4** The dielectric shield shall be visually inspected to confirm the dimensions are in accordance with the detailed design and that the installation complies with 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.

**8.4.1.5** All inspections and data shall be recorded on inspection and test plans in accordance with the quality plan.



### 8.4.2 Pre-energizing measurements

As soon as possible after the vessel is floated out from the dry dock, pre-energizing measurements shall be made and recorded in accordance with the quality plan prior to switching the cathodic protection system on, and shall include the following:

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

b) hull and appendage to seawater potentials with respect to portable reference electrodes;

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

### 8.4.3 Initial energizing

The cathodic protection system shall be energized (switched on) in accordance with the design requirements for initial polarization. Measurements shall be made and recorded in accordance with the quality plan and shall include the following:

a) The potential of the hull and fixtures to seawater with respect to all permanently installed reference electrodes.

b) The potential of the hull and fixtures to seawater with respect to all portable reference electrodes and coupons.

c) Confirmation of polarity. Confirmation of the correct output polarity for impressed current CP systems and power sources shall be undertaken. This is to confirm the correct polarity of the transformer-rectifier output and that cables are connected to the correct components. If any steel to seawater potential values shift in a positive direction they shall be immediately investigated to determine the requirements for additional testing and/or remedial works. Confirmation of correct output polarity shall be undertaken by personnel having the competency levels specified in Clause 4.

d) If any steel to seawater potential values shift in a positive direction they shall be investigated to determine any requirements for additional testing and/or remedial works;

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

### 8.4.4 Performance assessment

**8.4.4.1** Within one month of energizing, a survey shall be undertaken using a portable reference electrode to supplement the permanent monitoring provisions installed. The survey shall ensure that the criteria in 5.2 Cathodic Protection Criteria selected at the design stage are met at representative locations.

**8.4.4.2** 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.

NOTE Cu|$CuSO_4$ reference electrodes are not suitable for use in marine environments due to contamination by chloride ions, which makes the reference electrode unstable.

**8.4.4.3** A repeat survey as above should be undertaken one 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.

**8.4.4.4** 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 or as subsequently modified based upon performance of the system.

### 8.5.2 Galvanic anode systems

**8.5.2.1** 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 using a portable reference electrode.

**8.5.2.2** Following the commissioning testing in 8.3.1 galvanic systems further testing should be performed, typically between 9 months and 12 months and then at intervals of 2 years to 5 years subject to proven performance and planned dry docking intervals.

**8.5.2.3** 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 fixtures. If necessary, these anodes should be replaced. Attention should be given to potential surveys and diver inspection of sea chests.

### 8.5.3 Impressed current systems

**8.5.3.1** 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 downtime and confirming that all systems are functioning and all anode current outputs are similar to those recorded during the previous assessment.

**8.5.3.2** 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 polarization.

— 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;

— 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);

— measurement of potential difference between anodes and the hull to verify the metal to metal isolation of anode to hull.



The measurement electrodes shall be calibrated at regular intervals preferably not exceeding one year, by measuring their electrode/seawater potential with respect to a Ag/AgCl/0,5M KCl reference electrode or any other reference electrode recently calibrated.

**8.5.3.3** 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.

**8.5.3.4** 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 energized so that the necessary actions can be taken to ensure their safety.

### 8.5.4 Interaction with adjacent structures

**8.5.4.1** Interaction testing is not normally required in respect of ships due to their mobility. However, if a ship is laid up, or is berthed for long or repeated periods alongside quays or jetties, it is recommended that interaction testing should be carried out 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-to-electrolyte potentials greater than those permitted in EN 50162 shall be investigated and corrected.

**8.5.4.2** Adjacent structures fitted with cathodic protection shall not have their protection levels changed beyond the levels indicated in EN 50162 by the ship's cathodic protection systems. Adjacent structures not fitted with cathodic protection should not have their corrosion potentials changed by more than +20 mV by the new cathodic protection system as defined in EN 50162.

**8.5.4.3** 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 by the adjacent cathodic protection system.

## 8.6 Dry-docking period

**8.6.1** 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.

**8.6.2** 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 to avoid an electrical continuity due to salt deposits. Insulating resistance should be more than 1 MΩ.

NOTE 1 Insulating resistance will be low if there is moisture or a layer of water film between the hull and the impressed current anode or reference electrode.

NOTE 2 Insulation resistance of the anode holder or the reference electrode assembly will decrease over time due to water absorption.

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

**8.6.4** The coating should be visually examined to determine if the coating deterioration is within the value assumed in the cathodic protection design and if there is any evidence of coating damage caused by the cathodic protection.

**8.6.5** Inspection of the reference electrodes and anodes should be made. After re-floating all reference electrodes require recalibration (8.5.3.3)

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

## 9.1 Fitting out period

**9.1.1** 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 system.

**9.1.2** When it is intended that a ship is fitted with a galvanic 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.

**9.1.3** 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 polarization in accordance with this document. These anodes can be hauled on board if the vessel changes berth, and lowered again on arrival at the new position.

## 9.2 Lay-up period

**9.2.1** 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.

**9.2.2** 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.

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

**9.2.4** Vessels that are laid up and static for extended periods (years) might be subjected to marine growth colonization and microbially influenced corrosion (MIC). In these circumstances, the protection criteria shall be as for anaerobic conditions as in Table 1.



# 10 Documentation

## 10.1 Objectives

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

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

**10.1.3** The as-built documentation shall reflect any changes from the design specification including any variations in the equipment locations, deviations in water line and any other characteristic that can alter protected areas.

**10.1.4** Commissioning data shall include results of surveys conducted after energizing each cathodic protection zone to assess that each zone satisfies design criteria and operates effectively. Structure potential measurements are required 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 Galvanic anode systems

The following data shall be maintained for reference and shall be updated, 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 closed circuit potential;

— the number of anodes, their dimension, weight, specification, alloy composition, documented ampere-hour capacity measured during tests, and other characteristics, as well as the manufacturer/supplier references and documentation;

— coating data;

— 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;

— anode replacement history;

— monitoring equipment changes.

## 10.3 Impressed current system

The following data shall be maintained for reference and shall be updated, 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;

— coating data;

— 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 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 d.c. 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 d.c. 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, d.c. 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;

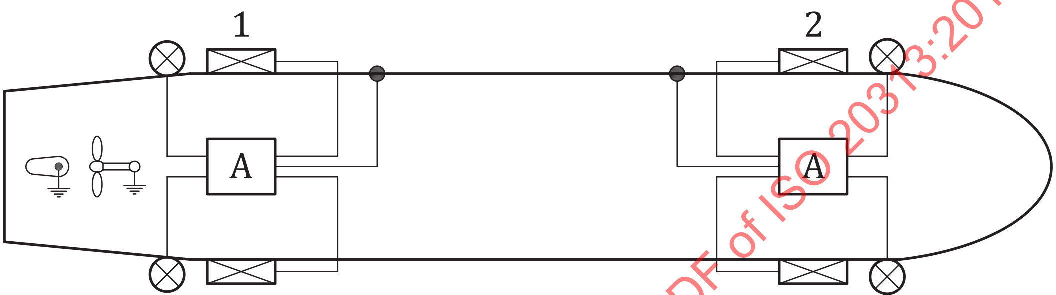
— an Operation and Maintenance Manual which shall detail the as-built system, inspection and testing procedures, inspection and testing intervals and provide a fault-finding guide. The data detailed above may in addition be incorporated into this volume;

— interaction testing results and any mitigation.

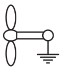
# Annex A
(informative)

# Impressed current system for external 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 |
| A | Protection current transformer rectifier with potentiostatic control. |
|  | Impressed current anode (inert). Electrically isolated from the hull. |
|  | Permanent reference electrode. Electrically isolated from the hull. |
|  | Propeller connection via shaft brush ring |
|  | Rudder grounding via cable. |

All hull penetrations to be via cofferdams (not shown).

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

# Annex B
(informative)

# Guidance on design current density values for cathodic protection of ship's hulls and tanks

## B.1 Recommended design current densities for the cathodic protection of bare steel ($J_b$) and for coated areas on a ship's hull

Cathodic current demand is calculated from the surface area multiplied by the selected current density and modified by the presence of coatings and their gradual breakdown. The current density can be that required for bare steel, in which case a coating breakdown factor has to be applied to any coated structure. Alternatively, a "global" approach can be adopted which assumes a defined coating breakdown appropriate for the intended dry docking (or maintenance) periods.

Current densities can be selected from previous history of cathodic protection system performance and experience. In the absence of documented and reliable performance data, the recommended current densities for both approaches given in Table B.1 can be used.

**Table B.1 — Recommended design current densities for protecting bare steel and for a global approach**

| Typical situation | Design current density ($mA.m^{-2}$) for bare steel | Global design current density[b] ($mA.m^{-2}$) for coated vessels at periods to maintenance (dry docking) | |
|---|---|---|---|
| | | Up to 3 years[c] | 5 years[d] |
| Near static[a] | | | |
| without tidal influence | 100 to 200 | 5 to 10 | 8 to 16 |
| with tidal influence | 150 to 250 | 7 to 13 | 12 to 20 |
| Moving vessel... | | | |
| speed <20 kn | 220 to 350 | 11 to 18 | 17 to 28 |
| speed ≥20 kn | 350 to 500 | 18 to 25 | 28 to 40 |
| Vessels in ice | 500 to 750 | 35 to 55 | 60 to 90 |
| Corrosion resistant alloys (CRA) including Propellers | >500 | N/A | N/A |
| Ballast tanks including slop tanks etc. | 90 to 130 | 10 | 15 |

[a] Includes buoys, pontoons and static barges. Values can vary with ambient temperature, i.e. geographical location.

[b] Current density values are presented as ranges rather than absolute values since a wide range of service conditions are possible. The CP designer shall determine the appropriate design value. (See 5.5.3.8).

[c] For a 2 year or 3 year drydocking interval using an illustrative coating breakdown of 2 % initial plus 1,2 % per year. See B.2 for coating breakdown guidance.

[d] For a 5-year dry docking interval using an illustrative coating breakdown of 2 % initial plus 1,2 % per year. See B.2 for coating breakdown guidance.

[e] Ten $m.s^{-1}$ is approximately 20 kn.

These current density values used for calculation will determine the current demand for cathodic protection. For coated structures, the initial current required for polarization is seldom important and the mean (design) current determines the current required to maintain polarization. When coating damage occurs, there should be sufficient output from galvanic anodes even when fully consumed to its designed utilization value to allow rapid repolarization to occur and the maximum current requirements (for galvanic anode calculation purposes) can be 20 % to 30 % higher than the design current.

Impressed current CP systems lead to a less efficient current distribution due to the smaller number of anodes although of much higher current output. An impressed current system should be designed to be able to provide a minimum of 25 % more than the calculated maximum protection current demand.

NOTE The current densities in Table B.1 relate to those required for bare carbon steel. However, in some ballast tanks Corrosion Resistant Alloys (CRAs) can be used, e.g. Cu/Ni heating coils.

CRA by themselves can require a similar current density to achieve corrosion control of the CRA material. When electrically bonded to a carbon steel alloy, however, the CRA has to be polarized close to the design protection potential of the steel to avoid galvanic attack and protect the steel. For the CRA this can require two to three times the current density required for corrosion control alone. These requirements should be considered by the designer.

Other bare metals such as cuprous alloys can use the same values as bare steel.

The current densities on CRAs are dependent upon water composition, dissolved oxygen levels, temperature and film forming capabilities of the solution. Produced water will invariably require lower current densities than seawater.

Values as given in Table B.1 can be used where a total surface area and coating breakdown approach is considered.

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

Initial coating breakdown factor: 1 % to 2 %.

Deterioration rate for coatings exposed to Im2 environment (as defined in ISO 12944-2) for various durabilities (as defined in ISO 12944-1):

— 3 % per year low durability coatings;

— 1,5 % per year for medium durability coatings;

— 0,5 % to 1 % per year for high durability coatings.

For high-speed ships [speeds above 12,86 m.s$^{-1}$ (25 knots)] and ships in harsh or ice service the annual coating breakdown rate may be higher.

# Annex C
(informative)

# Anode resistance, current and life duration formulae

## C.1 Anode resistance formulae

### C.1.1 General

Formulae given in this informative annex are those that are in general use. Other formulae can be considered based on 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 $L \geq 4r$

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

if $L \geq 4r$

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

where

$R_a$ is anode resistance in Ω;

$L$ is length in m;

$r$ is radius in m;

$\rho$ is seawater resistivity in Ω.m.

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 $R_a$ × 1,3. This simplification can be improved by mathematical modelling.

### C.1.3 Long flush mounted anodes on the structure steel surface where length ≥4 × width

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

$$R_a = \frac{\rho}{2S} \tag{C.3}$$

where

$\rho$ is seawater resistivity in Ω.m;

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

### C.1.4 Short flat plate mounted flush on the structure surface where length is <4 × width

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

$$R_a = 0{,}315 \frac{\rho}{\sqrt{A}} \qquad (C.4)$$

where

$R_a$ is the anode resistance in ohms;

$\rho$ is the environment resistivity in ohm metres;

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

### C.1.5 For closely spaced arrays of anodes

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

## 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:

$$W_{final} = W_{initial} \cdot (1 - u) \qquad (C.5)$$

where

$W$ is the net mass of anode alloy (excluding the steel core) in kilograms (kg);

$W_{initial}$ is the Initial Value;

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

$u$ is the utilization 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 utilization factor, which may be in the range of 0,70 to 0,95.

Calculation of end of life anode dimensions:

b) For slender anodes

$$L_{final} = L_{initial} \times 0{,}9 \qquad (C.6)$$

where

$L_{initial}$ is the initial value;

$L_{final}$ 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.

$$X_{final} = \frac{W_{final}}{d_{anode} \cdot L_{final}} + X_{core} \tag{C.7}$$

$$r_{final} = \sqrt{\frac{X_{final}}{\grave{A}}} \tag{C.8}$$

where

$X_{final}$ is the final (or end of life) value cross sectional area of the anode (including the core) in square metres ($m^2$);

$X_{core}$ is the cross sectional area of the core in square metres ($m^2$);

$d_{anode}$ specific gravity of the anode alloy in kilogram per cubic metre ($kg/m^3$);

$r_{final}$ 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.

1) For long flush mounted anodes

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

$$r_{final} = \sqrt{\frac{2 \cdot X_{final}}{\grave{A}}} \tag{C.9}$$

2) For short flush or bracelet anodes

Assume that the resistance does not change from the initial value.

## C.3 Electrolyte resistivity

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.

**Table C.1 — Resistivity in ohm.m (Ω.m) with respect to temperature**

| | Salinity (g.kg⁻¹ or 0/00) | | | | |
|---|---|---|---|---|---|
| Temperature °C | 20 | 25 | 30 | 35 | 40 |
| 0 | 0,573 | 0,468 | 0,396 | 0,344 | 0,304 |
| 5 | 0,496 | 0,405 | 0,344 | 0,299 | 0,265 |
| 10 | 0,435 | 0,356 | 0,302 | 0,263 | 0,233 |
| 15 | 0,385 | 0,315 | 0,268 | 0,233 | 0,207 |
| 20 | 0,345 | 0,282 | 0,240 | 0,209 | 0,185 |
| 25 | 0,311 | 0,255 | 0,216 | 0,189 | 0,167 |

NOTE After National Physics Laboratory/Kaye and Laby.

Electrolyte resistivity is of particular importance in the design of galvanic anode systems because the resistivity value has a significant effect on the calculated anode resistance and hence the calculated current output. The effect is less critical for impressed current anodes if the design provides for sufficient output voltage variation.

For brackish water, the resistivity may fluctuate greatly (typically 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.

Typical resistivity values:

— cold seawater: 0,30 Ω.m to 0,35 Ω.m

— warm seawater: 0,15 Ω.m to 0,25 Ω.m

— temperate brackish water: 1,00 Ω.m to 5,00 Ω.m

— fresh river water: 3,00 Ω.m to 30,00 Ω.m

## C.4 Galvanic anode current output

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

$$I = \frac{\Delta U}{R} \quad \text{(C.10)}$$

where

$I$ is the current output in amps;

$\Delta U$ is the driving voltage in volts;

$R$ is the circuit resistance in ohms;

$\Delta U$ is generally taken as the potential difference between the polarized potential of the steel (− 0,80 V with respect to Ag/AgCl/seawater) and the operating potential of the particular anode alloy in seawater (Typically −1,10 to −1,05 V for aluminium based alloys, −1,05 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).

For a ship's hull being protected to −0,80 V with respect to Ag/AgCl/seawater with zinc alloy anodes, $\Delta U$ will be in the range 0,20 V to 0,25 V.

## C.5 Galvanic anode life

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

$$T_{anode} = \frac{W_{anode} \cdot u}{E \cdot I_s} \tag{C.11}$$

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 utilization 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 utilization 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 $kg.A^{-1}.a^{-1}$ (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:

$$W_{total} = \frac{I_{mean} \cdot T_{design} \cdot 8\,760}{Q \cdot u} \tag{C.12}$$

where

$W_{total}$ is the minimum total net weight of galvanic anode material required, in kilograms (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 (a);

$u$ is the utilization 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 utilization factor, which may be in the range of 0,7 to 0,95;

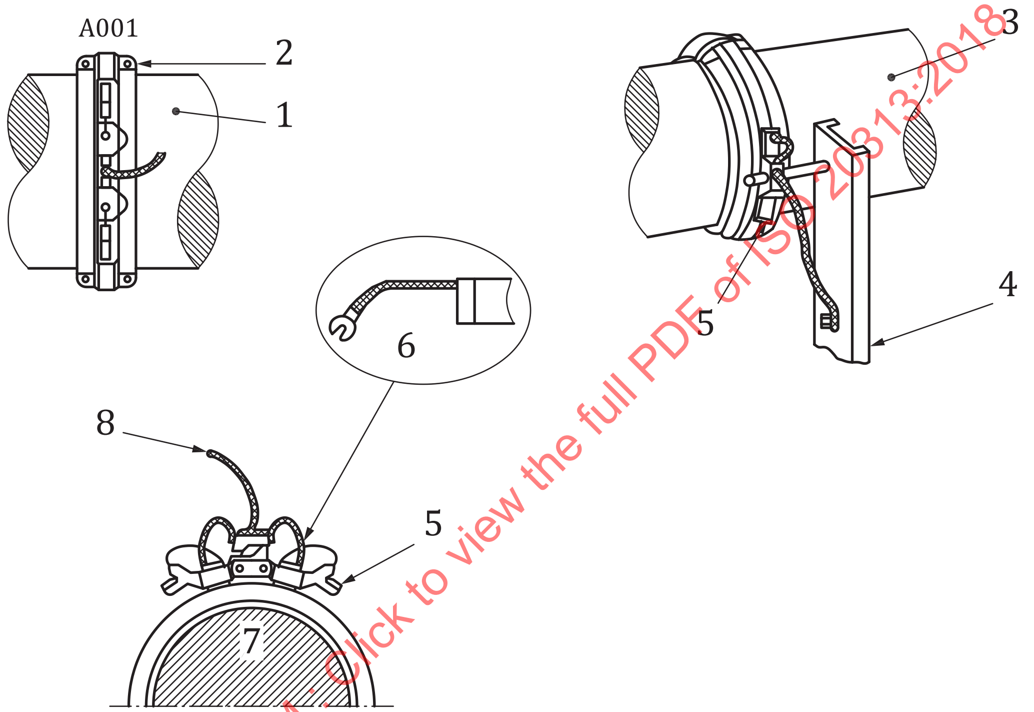
$Q$ is the practical anode capacity for the allode material in the environment considered, in ampere-hours per kilogram (Ah.kg-1) (see EN 12496);

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 Figure D.1 (for shaft) and Figure D.2 (for rudder).

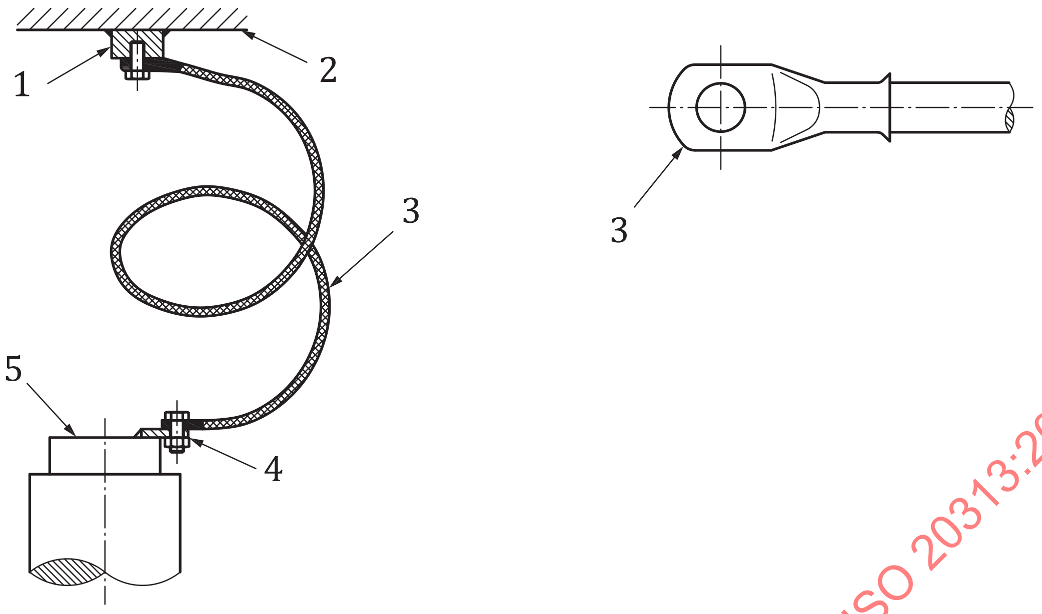





**Key**

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, preferably, 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**

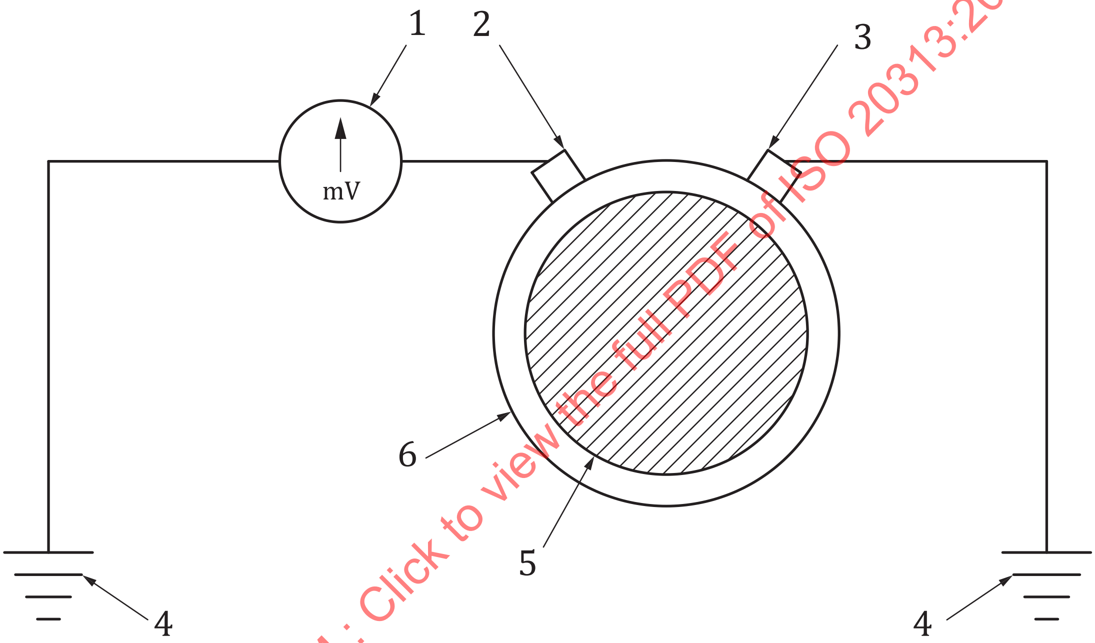


# Annex E
(informative)

## Monitoring of electrical bonding of a ship's propeller

A typical and optional arrangement useful for monitoring the quality of electrical bonding between 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 at maximum current output is acceptable.




**Key**

1 centre zero mv analogue meter or dvm
2 monitoring brush(es)
3 bonding brush(es)
4 hull structure
5 propeller shaft
6 slip-ring

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

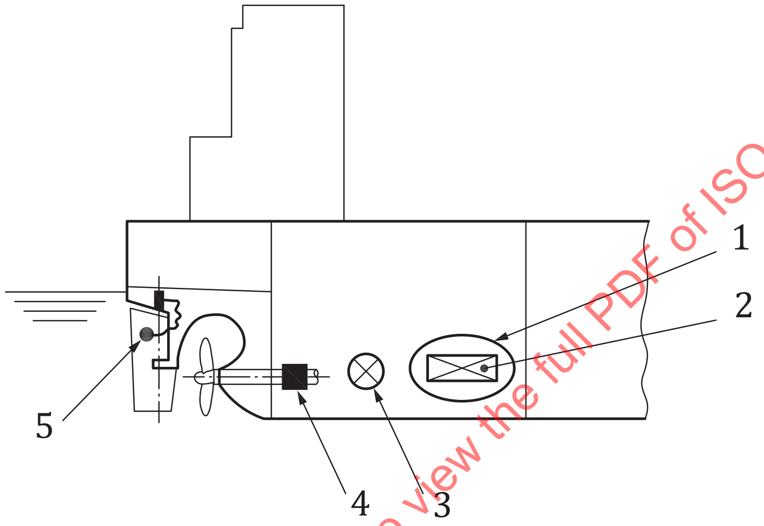


# Annex F
(informative)

# 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 propeller 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 shapes in Figure G.1. To avoid cavitation effects anodes should not be placed in the grey area shown. Recommended dimensions of the grey area are given in Figure G.2.

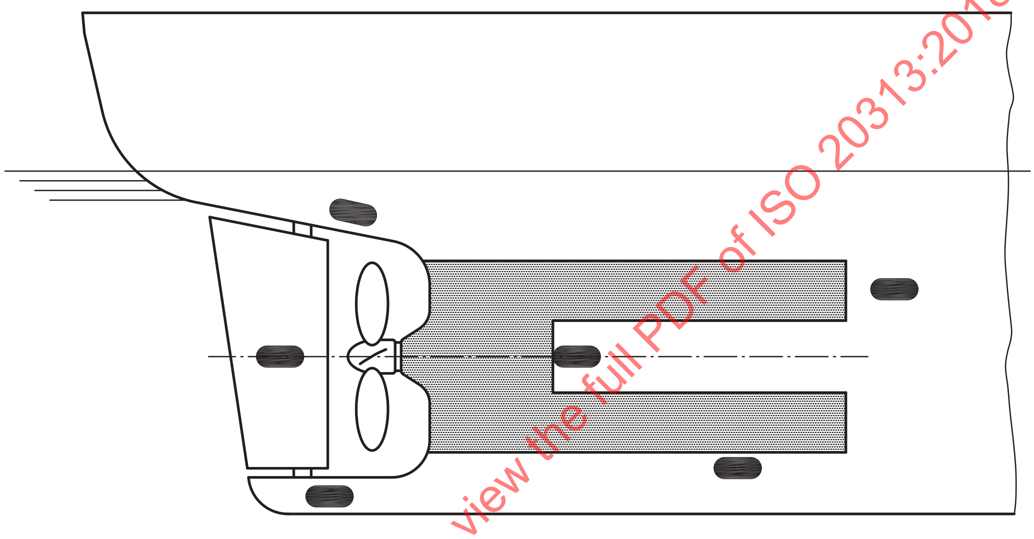


**Figure G.1 — Arrangement of galvanic anodes in vicinity of propeller**

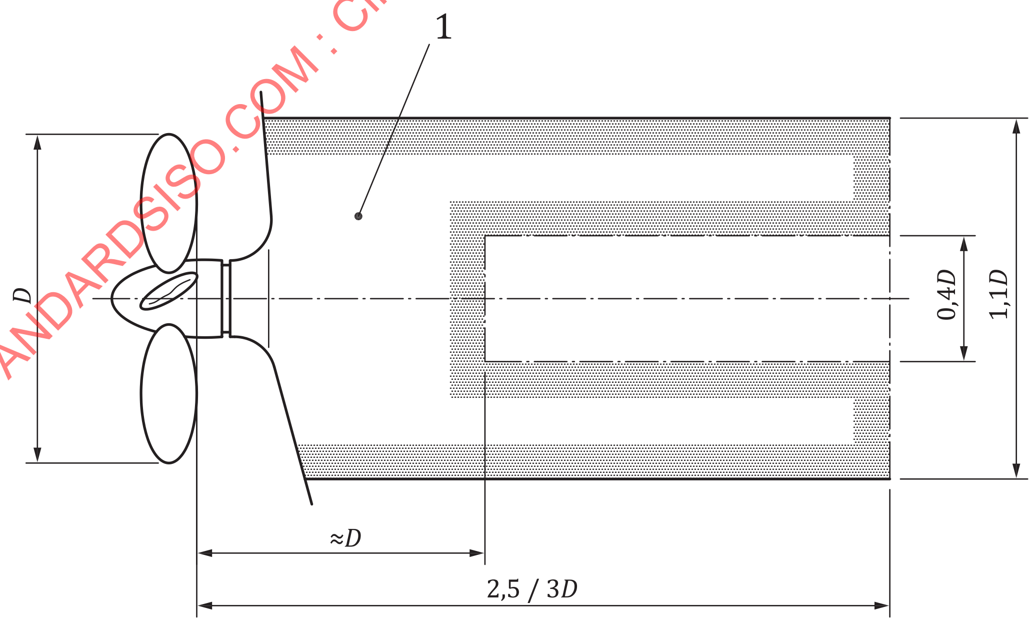



**Figure G.2 — Dimensions of the grey area (1) not recommended for location of anodes**



# Annex H
(informative)

# Electrochemical characteristics of impressed current anodes

This informative annex provides details of the most commonly used mixed metal oxide anodes (MMO). Other anode types can be used provided that they meet the mechanical and electrochemical performance requirements specified in the cathodic protection design.



## H.1 Properties of the MMO electro-catalytic coating

The electro-catalytic coating has the following physical-chemical properties:

1 A crystalline structure, with density ranging between 6 g.cm$^{-3}$ and 12 g.cm$^{-3}$

2 A metallic type of conduction: the resistivity is in the order of 1 × 10$^{-7}$ ohm.m

3 A high surface area to catalyse oxidation reactions

A typical MMO coating for anodes has a Tafel slope value ranging from 30 mV to 50 mV per decade and from 40 mV to 60 mV per decade for oxygen evolution. The values vary depending upon the MMO composition.

Variations are dependent on the specific environments where chlorine or oxygen is evolved.

### H.1.1 Current density

#### H.1.1.1 In seawater

The maximum recommended current density for MMO anodes in flowing seawater is 600 A.m$^{-2}$ Flowing seawater is defined by the following basic parameters:

1 Resistivity: max 0,35 Ω.m

2 Salinity: min 25 g.l$^{-1}$

3 Chlorinity: min 16 g.l$^{-1}$

4 Flow rate: min 0,01 m.s$^{-1}$

5 Temperature range: from 10 °C to 70 °C

#### H.1.1.2 In fresh and brackish waters

Fresh and brackish water are defined by the following basic parameters:

1 Resistivity range: from 0,35 Ω.m to 300 Ω.m

2 Temperature range: from 10 °C to 70 °C

The maximum recommended current density for MMO anodes in fresh water is 100 A.m$^{-2}$

The maximum recommended current density for MMO anodes in flowing brackish waters is 100 A.m$^{-2}$ but it may be increased up to 300 A.m$^{-2}$ depending on water chloride content and temperature.

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<br>($g.A^{-1}.a^{-1}$) | Maximum current density<br>($A.m^{-2}$) | Maximum voltage between anode material and electrolyte<br>(V) |
|---|---|---|---|
| Platinized titanium | 0,004 to 0,012[a] | 500 to 3 000 | 8[b] |
| Platinized niobium | 0,004 to 0,012[a] | 500 to 3 000 | 50 |
| Platinized tantalum | 0,004 to 0,012[a] | 500 to 3 000 | 100 |
| Mixed Metal Oxide (MMO) on titanium substrate | 0,000 5 to 0,001 | 400 to 1 000[c] | 8[b] |
| Lead silver[d] | 25 to 100 | 250 to 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 can break down if the anode potential exceeds 8 V with respect to Ag/AgCl/seawater electrode. Higher voltages may be used with fully platinized 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 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).