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Ships and marine technology — Cathodic protection of ships

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ISO copyright office
Ch. de Blandonnet 8 • CP 401
CH-1214 Vernier, Geneva, Switzerland
Tel. +41 22 749 01 11
Fax +41 22 749 09 47
copyright@iso.org
www.iso.org

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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).

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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 (V vs. Ag/AgCl/seawater)	Most negative potential (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 (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:

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

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