SLOVENSKI STANDARD
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Katodna zaščita notranjih površin kovinskih rezervoarjev, konstrukcij, opreme in cevovodov, ki vsebujejo morsko vodo

Cathodic protection of internal surfaces of metallic tanks, structures, equipment, and piping containing seawater

Kathodischer Schutz der inneren Oberflächen von metallischen Tanks, Strukturen, Ausrüstung und Rohrleitungen die Meerwasser enthalten

Protection cathodique des surfaces internes des réservoirs, ouvrages, équipements et tuyauteries métalliques contenant de l’eau de mer

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Cathodic protection of internal surfaces of metallic tanks, structures, equipment, and piping containing seawater

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This European Standard was approved by CEN on 11 November 2019.

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Contents

Page

European foreword

This document (EN 17243:2020) has been prepared by Technical Committee CEN/TC 219 “Cathodic protection”, the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by September 2020, and conflicting national standards shall be withdrawn at the latest by September 2020.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

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Introduction

Metallic structures containing seawater or brackish waters are exposed to the risk of corrosion. Even when a coating is applied to reduce this risk, cathodic protection (CP) is usually used to ensure corrosion control during the structure design life. This is especially important in the presence of galvanic couples between various metals and alloys because corrosion is then concentrated to the less noble material.

Cathodic protection works by supplying sufficient direct current to the internal surface of the structures in contact with water in order to change the structure to electrolyte potential to values where the corrosion rate is insignificant.

The general principles and theoretical aspects of cathodic protection in seawater are detailed in EN 12473.

1 Scope

This document specifies the requirements and recommendations for cathodic protection systems applied to the internal surfaces of metallic tanks, structures, equipment and piping containing natural or treated seawater or brackish waters to provide an efficient protection from corrosion.

Cathodic protection inside fresh water systems is excluded from this document. This is covered by EN 12499.

NOTE EN 12499 covers internal cathodic protection for any kind of waters, including general aspects for seawater but excluding industrial cooling water systems. This document specifically details applications in seawater and brackish waters.

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.

EN 12473, *General principles of cathodic protection in seawater*

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

EN 12499, *Internal cathodic protection of metallic structures*

EN 13509, *Cathodic protection measurement techniques*

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

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

EN ISO 15257, *Cathodic protection — Competence levels of cathodic protection persons — Basis for certification scheme (ISO 15257)*

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

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

3 Terms and definitions

For the purposes of this document the terms and definitions given in EN 12473 and EN 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 https://www.iso.org/obp/ui

3.1
anode redundancy factor
multiplier applied to the theoretical number of anodes to allow for anode damage and failures for ensuring that protection will continue to be achieved when one or more anodes are lost, without modifying the unit weight of anodes

3.2
back electro motive force
e.m.f
overvoltages generated at anode and cathode interfaces at the operating conditions

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

3.4
coating breakdown factor
f_c
ratio of cathodic current density for a coated metallic material to the cathodic current density of the bare material

3.5
critical crevice potential
potential more positive than the potential which there is a risk of initiation of crevice corrosion for a given environment and crevice geometry

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

3.7
over-polarization
occurrence in which the structure to electrolyte potentials are more negative than those required for satisfactory cathodic protection

Note 1 to entry: Over-polarization provides no useful function and can even cause damage to the structure such as cracking due to hydrogen embrittlement of sensitive materials or coating disbondment.

Note 2 to entry: Often incorrectly referred to as over-protection.

3.8
ullage factor
u_f
ratio of the surface area of a ballast tank which may be in contact with water to the total surface area

Note 1 to entry: When the entire surface area may be wetted, $u_f = 1$.

3.9
wetting factor
k
fraction of structure design life when the internal surface of a tank or a structure is in contact with water

Note 1 to entry: When the tank is permanently filled with water, $k = 1$.

Note 2 to entry: For changing conditions an average value can be considered.

Note 3 to entry: Also known as loading factor, see Reference [1] in the Bibliography.

3.10
hydrogen embrittlement
process resulting in a decrease of the toughness or ductility of a metal due to absorption of hydrogen

3.11
hydrogen stress cracking
HSC
cracking that results from the presence of hydrogen in a metal and tensile stress (residual and/or applied)

Note 1 to entry: HSC describes cracking in metals which may be embrittled by hydrogen produced by cathodic polarization without any detrimental effect caused by specific chemicals such as sulphides.

4 Competence of personnel

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

EN ISO 15257 constitutes a suitable method of assessing and certifying competence of cathodic protection personnel.

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

5 General considerations

5.1 Structures and equipment to be protected

This document applies to the internals of any metallic tanks, structures, equipment, and piping. Examples include ballast tanks, aboveground or buried storage tanks including firewater tanks, filters such as sand filters, heat-exchangers and condensers, flooded sections of harbour and lock gates, sea defence barriers, dolphins, and offshore wind turbine foundations.

This document applies to the external submerged areas of appurtenances and other independent equipment fitted within tanks, such as pumps and piping, when they are not electrically isolated from the structure. Where this document is applied to tanks, internal items that are integral to the tank, such as stiffeners, shall also be included

This document applies also to the internal cathodic protection of piping transporting seawater or brackish waters, including valves, pumps and fittings. In such applications, additional considerations are required for the design and installation of cathodic protection.

This document is also applicable for temporary cathodic protection systems used to prevent corrosion by seawater or brackish waters when structures are being hydrotested (see 7.3.4) and when filled tanks or other equipment is in storage before commissioning and operation.

5.2 Materials

This document covers the cathodic protection of structures fabricated from or containing low carbon steel, carbon manganese steel or cast iron. This document is applicable to coated and to bare structures.

This document also covers the cathodic protection of structures fabricated from or containing stainless steels, nickel alloys, copper alloys or titanium alloys. This document is applicable to coated and to bare structures.

The requirements and the recommendations for the cathodic protection systems described in this document are intended to ensure control over any galvanic coupling, which could be caused by the use of various metallic materials, and minimize risks due to hydrogen embrittlement or hydrogen stress cracking (see EN 12473).

5.3 Environment

This document is applicable only to structures containing seawater or brackish waters. Seawater may be either natural or treated (e.g. using chlorination systems) for preventing fouling of piping systems or for preserving biodiversity when ship ballast tanks are filled and emptied in various locations of the world, see Reference [2]. Special requirements can be necessary for structures containing polluted seawater or other fluids, e.g. slop tanks.

For surfaces which are alternately immersed and exposed to the atmosphere, cathodic protection is only effective when the structure is submerged and the immersion time is sufficiently long for the metal to remain polarized.

5.4 Safety and environmental protection

5.4.1 General

This document does not cover routine safety and environmental protection aspects which are not especially associated with cathodic protection. Safety requirements specific to the application of cathodic protection within the scope of this document are covered.

An environmental checklist is supplied in Annex A.

For impressed current cathodic protection systems (ICCP), automatic control of applied potential shall be used (see subclause 9.1). Provision shall be made to prevent sparking if the anode is energized outside liquid level. Procedures to be adopted may include positioning of the anode so that it is always submerged and/or incorporation of emergency shutdown procedures so that if the anode is temporarily exposed all DC current is disabled.

The use of impressed current systems and of some galvanic anodes can be prohibited for some applications, for instance when in the vicinity of tanks containing hydrocarbons (see subclause 8.5).

5.4.2 Evolution of dangerous gases

Cathodic protection will generate gaseous hydrogen and can generate oxygen and chlorine. Some mixtures of oxygen and hydrogen are explosive; chlorine can be toxic and corrosive.

The design and operation of the cathodic protection systems shall take these risks into account to ensure that harmful and dangerous levels of gas accumulation are not allowed to occur. This may include the control of potential and/or the use of ventilation systems.

With galvanic anodes, the selection of alloy material should be carried out to minimize the risk.

5.4.3 Release of hydrogen gas

For impressed current systems, and with galvanic anodes (particularly magnesium anodes), the polarization causes evolution of hydrogen gas on the protected structure. Thus, in situations such as closed tanks where hydrogen can collect, an explosion hazard can arise. To mitigate this hazard, it is necessary for all designs to include venting to prevent the build-up of a significant gaseous volume of hydrogen. Gas levels should be monitored.

The rate of hydrogen evolution is related to the structure to electrolyte potential. Where hydrogen evolution can produce an explosion hazard the structure to electrolyte potential shall be limited by design or control.

5.4.4 Chlorine evolution

For impressed current cathodic protection systems working in seawater and brackish waters, one of the anodic reactions results in the electrolytic formation of chlorine. Such a formation can cause physical discomfort or downstream corrosion effects.

NOTE References [3] and [4] of the Bibliography provide information on toxic levels.

Chlorine production is related to the operating potential and material of the Impressed Current Cathodic Protection (ICCP). In order to reduce chlorine production, the anode current density can be reduced at design stage.

5.4.5 Access and emptying

Before opening an enclosed structure the impressed current cathodic protection system shall be turned off. For galvanic and ICCP systems, the enclosure gas levels shall be declared safe.

6 Cathodic protection criteria

6.1 General

The criteria for cathodic protection shall be in accordance with EN 12473. The criteria are based on the structure to electrolyte potential and the measurement techniques used shall ensure that this is measured accurately (see subclause 10.2).

When different metals and alloys are in electrical continuity, the protection potential shall be the most negative one in order to prevent any galvanic corrosion of the less noble of them

A negative limit to the potential may be required depending upon the metallic material in order to avoid coating disbondment (see ISO 15711) [5] and/or adverse effects due to hydrogen evolution or high pH.

The potential criteria and limit values are expressed without IR errors. IR errors, due to cathodic protection current flowing through resistive electrolyte and surface films on the protected surface, are generally considered insignificant in marine applications. However, potential measurements using “Instant OFF” techniques or “coupon Instant OFF” techniques can be necessary in applications described in this document in order to adequately demonstrate the achievement of the protection criteria (see EN 13509). Particular attention should be given to this in brackish waters and sedimentary deposits or close to impressed current anodes.

The errors due to variations in salinity when using Ag/AgCl/sea water reference electrode in brackish waters shall be addressed (see EN 12473).

6.2 Carbon and low alloy steels

To ensure the protection of carbon and low alloy steels in aerated seawater a protection potential more negative than – 0,80 V with respect to (wrt) Ag/AgCl/sea water shall be achieved. This corresponds approximately to + 0,23 V when measured with respect to a pure zinc electrode (e.g. alloy type Z2 as defined in EN 12496) or + 0,25 V when measured with respect to a zinc electrode made with galvanic anode alloy types Z1, Z3 or Z4 as defined in EN 12496.

When the water temperature or surface temperature of steel is higher than 60 °C, the criterion shall be – 0,90 V wrt Ag/AgCl/sea water. Between 40 °C and 60 °C the protection potential shall be interpolated between −0,80 and −0,90 V wrt Ag/AgCl/sea water.

For tanks and structures containing seawater or brackish where the electrolyte is not frequently renewed (e.g. less than once a month) the criterion for anaerobic conditions, i.e. – 0,90 Vwrt Ag/AgCl/sea water, shall be adopted regardless of temperature.

6.3 Stainless steels and nickel alloys

In chloride-containing aerated environments such as natural seawater and brackish waters, stainless steels are known to resist uniform corrosion and the possibility for crevice corrosion and pitting remains the principal concern. To ensure the protection of such alloys in these environments, the protection potentials given in EN 12473 apply, i.e. −0,30 V wrt Ag/AgCl/sea water for stainless steels with PREN ≥ 40 and −0,50 V wrt Ag/AgCl/sea water for stainless steels with PREN < 40.

However, less conservative criteria can be used provided that these are justified and documented. In this case, the selected protection criteria shall be more negative than the critical crevice potential determined for a combination of a particular alloy (PREN, microstructure, etc.), crevice parameters (geometry, surface finish, type of gaskets, sealing pressure of flanges, etc.), and operating environmental conditions (composition, temperature, velocity, etc.).

The determination of the critical crevice potential shall be carried out on the basis of demonstrated service feedback and/or on laboratory tests relevant to the service conditions. In the absence of a more relevant method for a given practical situation, the methods given in the References [6][7][8] should be used.

In the case of galvanic couples between parts in stainless steel or nickel alloy and parts in carbon and low alloy steel, the protection potential criterion of the carbon and low alloy steel shall be more negative than – 0,80 V wrt Ag/AgCl/sea water.

In chlorinated seawater, the recommended protection potentials criteria for stainless steels and nickel alloys are the same as those in natural seawater, but the protection current densities can be less (see subclause 7.2.7).

6.4 Cracking risks induced by over polarization

Where there is a risk of hydrogen embrittlement or HSC of high strength steels or other metals which may be adversely affected by cathodic protection to excessively negative values, a less negative potential limit shall be defined and applied. If there is insufficient information for a given material, this specific negative potential limit shall be determined relative to the metallurgical and mechanical conditions by testing. Refer to EN 12473 for more details.

For carbon and low alloy steels, a potential negative limit of – 1,10 V wrt Ag/AgCl/sea water is recommended in order to minimize cathodic disbondment. Other potential negative limits shall be applied to prevent HSC of vulnerable metal compositions (refer to EN 12473).

For stainless steels and nickel alloys, ferritic and martensitic microstructures can suffer from hydrogen embrittlement when the potentials are too negative. Potentials more negative than the particular limit values should be avoided. EN 12473 gives information on this risk and also provides recommendations for qualification of the materials.

Titanium and its alloys are prone to titanium hydride formation in cathodic protection applications. This hydride can lead to cracking when stresses reach a critical level.

Heat exchanger tube inlets are areas of high mechanical stress due to construction methods. When heat exchanger tubes are swaged into the tube sheets the tubes may be subject to high residual stress.

Titanium grade 2 tubes should not be subject to a potential more negative than – 0,75 V wrt Ag/AgCl/sea water [9], some more conservative figures being found in the literature, see References [10][11], e.g. – 0,70 V [12] and even −0,65 V [13].

This conservative approach can be replaced by other criteria provided that these are justified and documented by an assessment to ensure that the risk is acceptable. Such an assessment shall consider all load contributions causing stress and strain. In any case, potential of the titanium shall not be more negative than – 1,00 V wrt Ag/AgCl/seawater as specified in EN 12499 and documented in the literature, see Reference [9].

For other applications where stresses and strains are lower, e.g. tubular plates, a negative limit of – 1,05 V wrt Ag/AgCl/seawater is sufficiently conservative, see Reference [14].

7 Design

7.1 General considerations

The objective of a cathodic protection system is to deliver sufficient current to each part of the internal surfaces of metallic tanks and structures, including bonded equipment, to achieve the protection criteria defined in Clause 6. This current should be distributed so that the structure to electrolyte potential of each part is within the limits given by the protection criteria during its normal service conditions (see Clause 6). Permanent reference electrodes should be installed to allow measurement of the potentials at selected locations.

Uniform levels of cathodic protection may be difficult to achieve in some areas or parts of structures. In this case the use of reference electrodes installed in shielded areas is recommended, especially for assisting the commissioning. The cathodic protection system for tanks and structures is generally combined with a protective coating system, even though some equipment such as pumps and small pipes may not be coated. A good coating is especially recommended when temperature and/or velocity of the water is high, such as in pipeline systems or heat-exchanger cooling water boxes.

In the absence of instructions for the design life of the cathodic protection system, it shall be designed either for the structure design life or for a period corresponding to a planned maintenance, such as dry-docking interval in the case of ballast tanks on ships or floating offshore structures. Alternatively, when it is not feasible to design the cathodic protection system for the structure design life or if planned maintenance is not possible, the system should be designed for easy replacement of cathodic protection components. Access fittings allowing replacement of anodes and reference electrodes can be considered, e.g. for pipeline systems.

Where small current demands are anticipated over the entire structure design life, cathodic protection can be achieved by galvanic anode systems. Impressed current systems are generally used for other instances, such as higher current demand, temporary protection of large equipment containing seawater or brackish water for hydrotesting, pipe systems or water boxes of large heat-exchangers.

Each stage of the design, the installation, the energizing, the commissioning, the long-term operation and the records of all the elements of cathodic protection systems shall be documented and maintained.

Each part of the work should be undertaken in accordance with a quality plan.

NOTE EN ISO 9001 [15] constitutes a suitable Quality Management Systems Standard.

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

All the documentation required in the above shall constitute part of the permanent records.

7.2 Design parameters

7.2.1 General

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

a) Determine the coated and non-coated areas exposed to water;

b) Determine the maximum and mean current demands for each of these areas taking into account temperature and velocity of the water;

c) Determine the type of cathodic protection system (galvanic, impressed current, or hybrid);

d) Determine the size, shape and number of anodes required to last the design life of the cathodic protection system in order to deliver the required distribution of current and to meet any constraint of the structure

e) Determine anode locations and installation;

f) Determine reference electrodes types, location and installation.

The design of a cathodic protection system shall demonstrate that each structure subdivision is supplied with the cathodic protection current necessary to provide cathodic protection to meet the criteria in Clause 6 for all service conditions.

The anode distribution shall take into account the location of interfaces between dissimilar metallic materials.

Two different values shall be considered:

— I_{max}: maximum current demand, which corresponds to the most severe working conditions (e.g. end of life coating breakdown factor and maximum surface areas, maximum water temperature and velocity) and is used to design the maximum current required to be available from the cathodic protection system;

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

For optimizing the design, the following should be specified:

— maximum and minimum resistivity, temperature and velocity of the water;

— design life of the cathodic protection system;

— initial current density necessary to achieve initial polarization of the structure, j_{i};

— maintenance current density necessary to maintain polarization of the structure, j_{m};

— mean coating breakdown factor, f_{cm};

— final coating breakdown factor, f_{cf}.

NOTE As the initial polarization period before the steady-state is normally short compared to the structure design life, the mean current density over the structure design life is usually very close to the maintenance current density.

Indicative values for maintenance and initial protective current densities and mean and final coating breakdown factors of conventional paint systems are given in Annex B.

The units shall be consistent in the following calculations and follow the state of the art in the field of engineering.

7.2.2 Subdivision of the surfaces to be protected

Items to be protected should be divided into different cathodic protection zones to ensure a good current distribution, which can be considered independently with respect to cathodic protection design, although they may not necessarily be electrically isolated.

NOTE Complex geometries such as those encountered at the bottom of ballast tanks due to the presence of stiffeners constitute a typical example.

Each cathodic protection zone may consist of several components, the parameters of which should be identified, including material (steel, cast iron, etc.), surface area and coating characteristics if any (type, lifetime and coating breakdown factor).

7.2.3 Effective surface areas to be considered for calculations

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 computer aided systems.

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 of the top of the tank or of the structure.

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 and, secondly, the wetting factor (k), which determines for what proportion of the structure design life the surfaces will be wetted. These two factors will allow the mean surface area (S_{mean}) to be calculated and used for the determination of the mean current demand for tanks with varying levels. The mean surface area is the maximum surface area (S_{max}) multiplied by an ullage factor (u_{f}) and a wetting factor (k).

$$S_{\text{mean}} = S_{\text{max}} \cdot u_{\text{f}} \cdot k \tag{1}$$

In the case of heat-exchanger water boxes, the tube sheets, which are generally made of uncoated copper alloy, titanium or stainless steel, consume the major part of the protective current as compared to the surface of the coated steel water box. A current drain to the heat exchanger tubes shall also be taken into account.