BS EN 12473:2014

BSI Standards Publication

General principles of cathodic protection in seawater

bsi.

...making excellence a habit.™

Document Sharing Hub

Full document details: BS EN 12473:2014

National foreword

This British Standard is the UK implementation of EN 12473:2014. It supersedes BS EN 12473:2000 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee GEL/603, Cathodic protection.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

© The British Standards Institution 2014. Published by BSI Standards Limited 2014

ISBN 978 0 580 77497 3

ICS 47.020.01; 77.060

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 28 February 2014.

Amendments issued since publication

Date	Text affected

Documents
Document Sharing Hub

Full document details: BS EN 12473:2014

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 12473

February 2014

ICS 47.020.01; 77.060

Supersedes EN 12473:2000

English Version

General principles of cathodic protection in seawater

Principes généraux de la protection cathodique en eau de mer

Allgemeine Grundsätze des kathodischen Korrosionsschutzes in Meerwasser

This European Standard was approved by CEN on 16 November 2013.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.

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

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

© 2014 CEN All rights of exploitation in any form and by any means reserved worldwide for CEN national Members.

Ref. No. EN 12473:2014 E

Documents
Document Sharing Hub

Full document details: BS EN 12473:2014

Contents

Page

Foreword 4

1 Scope 5

2 Normative references 5

3 Terms, definitions, abbreviations and symbols 5

4 Application of cathodic protection in seawater 9
4.1 General 9
4.2 Galvanic anode method 9
4.3 Impressed current method 10
4.4 Hybrid systems 10

5 Determination of level of cathodic protection 12
5.1 Measurement of protection level 12
5.2 Reference electrodes 12
5.3 Potentials of reference electrodes 12
5.4 Verification of reference electrodes 12
5.5 Potential measurement 12

6 Cathodic protection potential criteria 13
6.1 General 13
6.2 Carbon-manganese and low alloy steels 13
6.3 Other metallic materials 15
6.3.1 General 15
6.3.2 Stainless steels 15
6.3.3 Nickel alloys 16
6.3.4 Aluminium alloys 16
6.3.5 Copper alloys 17

7 Design considerations 17
7.1 Introduction 17
7.2 Technical and operating data 17
7.2.1 Design life 17
7.2.2 Materials of construction 17
7.3 Surfaces to be protected 18
7.4 Protective coatings 18
7.5 Availability of electrical power 18
7.6 Weight limitations 18
7.7 Adjacent structures 18
7.8 Installation considerations 18
7.9 Current demand 19

8 Effect of environmental factors on current demand 19
8.1 Introduction 19
8.2 Dissolved oxygen 19
8.3 Sea currents 19
8.4 Calcareous deposits 19
8.5 Temperature 20
8.6 Salinity 20
8.7 pH 21
8.8 Marine fouling 21
8.9 Effect of depth 21
8.10 Seasonal variations and storms 21

Documents
Document Sharing Hub

Full document details: BS EN 12473:2014

9 Secondary effects of cathodic protection 21
9.1 General 21
9.2 Alkalinity 22
9.3 Environmentally-assisted cracking 22
9.3.1 General 22
9.3.2 Hydrogen embrittlement 22
9.3.3 Corrosion fatigue 22
9.4 Chlorine 23
9.5 Stray currents and interference effects 23

10 Use of cathodic protection in association with coatings 24
10.1 Introduction 24
10.2 Coating selection 24
10.3 Coating breakdown 25

Annex A (informative) **Corrosion of carbon-manganese and low-alloy steels** 26
A.1 Nature of metallic corrosion 26
A.2 Polarization 27

Annex B (informative) **Principles of cathodic protection** 30

Annex C (informative) **Reference electrodes** 33
C.1 General 33
C.2 Silver/silver chloride/seawater electrode 33
C.3 The zinc/seawater electrode 35
C.4 Verification of reference electrodes 35

Annex D (informative) **Corrosion of metallic materials other than carbon-manganese and low-alloy steels typically subject to cathodic protection in seawater** 37
D.1 Stainless steels 37
D.2 Nickel alloys 37
D.3 Aluminium alloys 37
D.4 Copper alloys 38

Bibliography 39

Documents
Document Sharing Hub
Full document details: BS EN 12473:2014

Foreword

This document (EN 12473:2014) 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 August 2014, and conflicting national standards shall be withdrawn at the latest by August 2014.

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

This document supersedes EN 12473:2000.

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Documents
Document Sharing Hub
Full document details: BS EN 12473:2014

1 Scope

This European Standard covers the general principles of cathodic protection when applied in seawater, brackish waters and marine mud. It is intended to be an introduction, to provide a link between the theoretical aspects and the practical applications, and to constitute a support to the other European Standards devoted to cathodic protection of steel structures in seawater.

This European Standard specifies the criteria required for cathodic protection. It provides recommendations and information on reference electrodes, design considerations and prevention of the secondary effects of cathodic protection.

The practical applications of cathodic protection in seawater are covered by the following standards:

— EN 12495, *Cathodic protection for fixed steel offshore structures*;

— EN ISO 13174, *Cathodic protection of harbour installations (ISO 13174);*

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

— EN 13173, *Cathodic protection for steel offshore floating structures*;

— EN 16222, *Cathodic protection of ship hulls*;

— EN 12474, *Cathodic protection of submarine pipelines*;

— ISO 15589-2, *Petroleum, petrochemical and natural gas industries — Cathodic protection of pipeline transportation systems — Part 2: Offshore pipelines*.

For cathodic protection of steel reinforced concrete whether exposed to seawater or to the atmosphere, EN ISO 12696 applies.

2 Normative references

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

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

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

3 Terms, definitions, abbreviations and symbols

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

NOTE The definitions given below prevail on their versions in EN ISO 8044.

3.1
acidity
presence of an excess of hydrogen ions over hydroxyl ions (pH < 7)

3.2
alkalinity
presence of an excess of hydroxyl ions over hydrogen ions (pH > 7)

Documents
Document Sharing Hub
Full document details: BS EN 12473:2014

3.3
anaerobic condition
absence of free oxygen dissolved in the electrolyte

3.4
calcareous deposits
minerals precipitated on the metallic cathode because of the increased alkalinity caused by cathodic protection

3.5
cathodic disbondment
failure of adhesion between a coating and a metallic surface that is directly attributable to the application of cathodic protection

3.6
cathodic protection system
entire installation that provides cathodic protection

Note 1 to entry: It may include anodes, power source, cables, test facilities, isolation joints, electrical bonds.

3.7
coating breakdown factor
fc
ratio of cathodic current density for a coated metallic material to the cathodic current density of the bare material

3.8
copper/copper sulphate reference electrode
reference electrode consisting of copper in a saturated solution of copper sulphate

3.9
dielectric shield
alkali resistant organic coating applied to the structure being protected in the immediate vicinity of an impressed current anode to enhance the spread of cathodic protection and minimize the risk of hydrogen damage to the protected structure in the vicinity of the anode

3.10
driving voltage
difference between the structure/electrolyte potential and the anode/electrolyte potential when the cathodic protection is operating

3.11
electro-osmosis
passage of a liquid through a porous medium under the influence of a potential difference

3.12
environmentally assisted cracking
cracking of a susceptible metal or alloy due to the conjoint action of an environment and stress

3.13
groundbed
system of immersed electrodes connected to the positive terminal of an independent source of direct current and used to direct the cathodic protection current onto the structure being protected

3.14
hydrogen embrittlement
process resulting in a decrease of the toughness or ductility of a metal due to absorption of hydrogen

Documents
Document Sharing Hub
Full document details: BS EN 12473:2014

3.15
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.

3.16
isolating joint (or coupling)
electrically discontinuous joint or coupling between two lengths of pipe, inserted in order to provide electrical discontinuity between them

3.17
master reference electrode
reference electrode, calibrated with the primary calibration reference electrode, used for verification of reference electrodes used for field or laboratory measurements

3.18
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 might even cause damage to the structure.

3.19
pitting resistance equivalent
PREN
indication of the resistance of a corrosion resistant alloy to pitting in the presence of water, chlorides and oxygen or oxidation environment, accounting for the beneficial effects of nitrogen

Note 1 to entry: For the purposes of this standard, PREN is calculated as follows:

$$PREN = \% Cr + 3{,}3[(\% Mo) + 0{,}5 (\% W)] + 16 (\% N).$$

3.20
potential gradient
difference in potential between two separate points in the same electric field

3.21
primary calibration reference electrode
reference electrode used for calibration of master reference electrodes is the normal hydrogen electrode (N.H.E.)

Note 1 to entry: The official reference electrode, standard hydrogen electrode (S.H.E.), which considers the fugacity coefficient for hydrogen gas and the activity coefficient for H^+ ions, is practically impossible to manufacture.

3.22
protection current
current made to flow into a metallic structure from its electrolytic environment in order to achieve cathodic protection of the structure

3.23
reference electrode
electrode having a stable and reproducible potential that is used as a reference in the measurement of electrode potentials

Documents
Document Sharing Hub
Full document details: BS EN 12473:2014

Note 1 to entry: Some reference electrodes use the electrolyte in which the measurement is carried out. Their potential varies according to the composition of this electrolyte.

3.24
resistivity (of an electrolyte)
resistivity is the resistance of an electrolyte of unit cross section and unit length

Note 1 to entry: It is expressed in ohm.metres (Ω.m). The resistivity depends, amongst other things, upon the amount of dissolved salts in the electrolyte.

3.25
saturated calomel reference electrode
reference electrode consisting of mercury and mercurous chloride in a saturated solution of potassium chloride

3.26
silver/silver chloride reference electrode
reference electrode consisting of silver, coated with silver chloride, in an electrolyte containing a known concentration of chloride ions

Note 1 to entry: Silver/silver chloride/ saturated KCl electrodes are electrodes currently used in the laboratory and for master reference electrode.

Note 2 to entry: Silver/silver chloride/seawater (Ag/AgCl/seawater) electrodes are electrodes currently used for field measurements in seawater.

3.27
slow strain rate test
test for evaluating susceptibility of a metal to environmentally assisted cracking (3.12 in this document) that most commonly involves pulling a tensile specimen to failure in a representative environment at a constant displacement rate chosen to generate nominal strain rates usually in the range 10^{-5} s^{-1} to 10^{-8} s^{-1}

Note 1 to entry: Slow strain rate testing may also be applied to other specimen geometries, e.g. bend specimens.

3.28
specified minimum yield strength
SMYS
minimum yield strength prescribed by the specification under which steel components are manufactured, obtained through standard analysis and representing a probabilistic value

Note 1 to entry: It is an indication of the minimum stress steel components may experience that will cause plastic (permanent) deformation (typically 0,2 %).

3.29
stray currents
current flowing through paths other than the intended circuits

3.30
structure to electrolyte potential
difference in potential between a structure and a specified reference electrode in contact with the electrolyte at a point sufficiently close to, but without actually touching the structure, to avoid error due to the voltage drop associated with any current flowing in the electrolyte

3.31
sulphate reducing bacteria
SRB
group of bacteria that are found in most soils and natural waters, but active only in conditions of near neutrality and absence of oxygen and that reduce sulphates in their environment, with the production of sulphides and accelerate the corrosion of structural materials

Documents
Document Sharing Hub
Full document details: BS EN 12473:2014

3.32
telluric currents
electrical currents induced by time varying changes in the earth's magnetic field

Note 1 to entry: They are able to flow in metallic conductors laid in the soil or in the sea.

3.33
zinc reference electrode
electrode consisting of pure zinc or zinc alloy specific for anodes in contact with the electrolyte in which the measurements are carried out

Note 1 to entry: Zinc reference electrodes are currently used for measurements in seawater carried out at permanent locations.

4 Application of cathodic protection in seawater

4.1 General

Metallic materials in aqueous environments such as seawater are susceptible to corrosion produced by electrochemical reactions. General information on corrosion of carbon-manganese or low alloy steels is given in Annex A.

Cathodic protection is an electrochemical corrosion prevention system based on the decrease of corrosion potential to a level at which the corrosion rate of the metal is significantly reduced (EN ISO 8044). For industrial structures, residual corrosion rates less than 10 µm / yr are typically achieved with a fully effective cathodic protection system.

Cathodic protection is achieved by applying a voltage able to supply sufficient current to the metallic surface to lower the potential. General information on the principles of cathodic protection is given in Annex B.

There are two methods whereby the protection current can be supplied to polarize the surface:

a) galvanic anode systems in which the current for protection is provided by a metal of more negative corrosion potential than the item to be protected i.e. aluminium, zinc and magnesium alloys for steel and iron for copper and copper based alloys,

b) impressed current systems in which direct current (normally produced from alternating current by a transformer rectifier) is used in conjunction with relatively inert anodes such as graphite, thin coatings of platinum or activated mixed metal oxides on metals such as titanium or niobium, lead alloys, silicon-iron, etc; in some cases a consumable anode such as scrap iron or steel is used.

4.2 Galvanic anode method

If two dissimilar metals are connected in the same electrolyte, a galvanic cell is produced. The open circuit voltage is the natural potential difference which exists between the two metals. If the circuit is closed, the potential difference drives an electrical current. The more negative electrode behaves as an anode and it releases electrons to the circuit and dissolves more rapidly while the more positive electrode behaves as a cathode and dissolves less readily. The use of galvanic anodes in cathodic protection is based on this phenomenon.

Assuming the structure to be protected is made of steel, aluminium or zinc alloy galvanic anodes can be used to form the cell, because these alloys are less noble (more electronegative) than steel. Anode attachment to the structure is made through a steel core on to which the anode material is cast. Thus the structure is in metallic contact with the anode material and also in electrolytic contact with it once the structure is immersed. This is represented in Figure 1, where it is seen that the electrons released by the dissolution of metal atoms are consumed in the cathodic reduction of oxygen on the structure and hydroxyl ions are produced at the structure surface.

AVA Documents
Document Sharing Hub

Full document details: BS EN 12473:2014

4.3 Impressed current method

Most impressed current anodes are of a type that do not dissolve readily on anodic polarization but sustain alternative reactions which involve decomposition of the aqueous environment, or oxidizing of dissolved chloride ions in it, i.e:

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^- \quad (1)$$

$$2Cl^- \rightarrow Cl_2 + 2e^- \quad (2)$$

Figure 2 represents an impressed current cathodic protection system using an inert anode in seawater where in the secondary reactions hydrogen and chlorine are evolved.

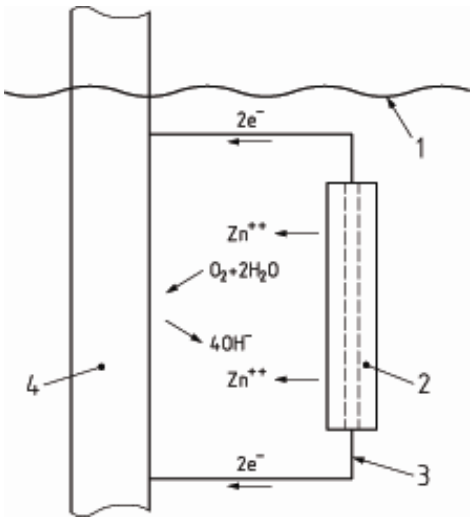
The advantages of the impressed current system are that it is possible to have a large adjustable driving voltage so that relatively few anodes need to be installed even to protect large uncoated structures in comparatively high resistivity environments. A comparison of galvanic and impressed current anode systems is given in Table 1.

4.4 Hybrid systems

These comprise a combination of galvanic anodes and externally powered impressed current anodes.

Because there can be a significant time between the initial immersion of a structure and the full commissioning of the impressed current system it is usual to fit sufficient galvanic anodes to polarize the critical region of the structure.

The galvanic anodes should also provide protection when the impressed current system is shut down for subsea survey and maintenance during the life of the structure.

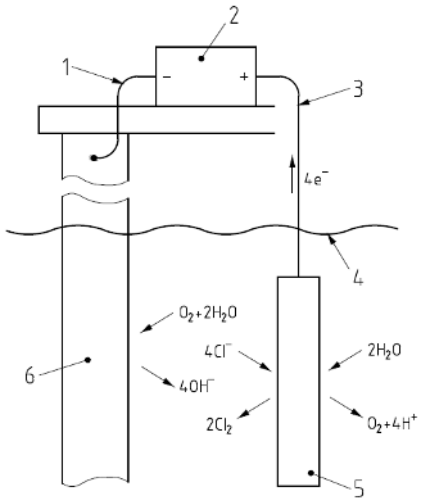


Key

1 seawater
2 galvanic anode
3 anode attachment
4 protected structure in seawater

Figure 1 — Representation of cathodic protection using a galvanic anode on a structure in the seawater

Documents
Document Sharing Hub
Full document details: BS EN 12473:2014



Key

1	insulated cathode cable	2	power supply (dc)	3	insulated anode cable
4	seawater	5	impressed current anode	6	protected structure in seawater

Figure 2 — Representation of impressed current cathodic protection using inert anode in seawater

Table 1 — Comparison of galvanic and impressed current systems

	Galvanic systems	**Impressed current systems**
Environment	Use can be impracticable in soils or waters of high resistivity.	Use is not restricted by resistivity of soils or waters
Installation	Simple to install.	Needs careful design otherwise can be complicated.
Power source	Independent of any source of electric power. Cannot be wrongly connected electrically.	External supply necessary. Care needs to be taken to avoid electrical connection in wrong direction.
Anodes	Bulk of anode material can restrict water flow and introduce turbulence and drag penalties.	Usually lighter and few in number. Anodes can be designed to have minimum effect on water flow.
Control	Tendency for their current to be self adjusting.	Controllable. Control usually automatic and can be continuous.
Interaction	They are less likely to affect any neighbouring structures.	Effects on other structures situated near the anodes need to be assessed.
Maintenance	Generally not required. May be renewed in some circumstances.	Equipment designed for long life but regular checks required on electrical equipment in service. Continual power required.
Damage	Anodes are robust and not very susceptible to mechanical damage. Where a system comprises a large number of anodes, the loss of a few anodes has little overall effect on the system. Connections have to be able to withstand any forces applied to the structure. Electrical insulation of cables is not necessary.	Anodes lighter in construction and therefore less resistant to mechanical damage. Loss of anodes can be more critical to the effectiveness of a system. Complete electrical insulation of positive cables exposed to electrolyte is mandatory.

AVA Documents
Document Sharing Hub

Full document details: BS EN 12473:2014

5 Determination of level of cathodic protection

5.1 Measurement of protection level

To determine whether a structure is adequately protected it is necessary to measure the metallic material/seawater potential. To achieve this, connections shall be made to both the structure and the electrolyte. The connection to the structure is a simple metallic one but for the connection to the electrolyte, a metal conductor has to be introduced into the electrolyte. This conductor introduces its own electrode potential, which inevitably becomes included in the measured value. This situation can be resolved by using a conductor of reproducible and defined electrode potential; this is called a reference electrode.

5.2 Reference electrodes

Most often, the reference electrodes used in the field are electrodes such as silver/silver chloride/seawater electrodes or high purity or anode alloy specification zinc electrodes. These electrodes are considered sufficiently accurate for most practical purposes even if the electrolyte is not fully defined and reproducible.

NOTE Saturated calomel electrode or silver/silver chloride/potassium chloride electrodes are not often used for monitoring and controlling cathodic protection systems in seawater, because they are insufficiently robust for field use. In addition, calomel electrodes are not considered acceptable for environmental reasons.

Details of the reference electrodes for marine applications are given in Annex C.

5.3 Potentials of reference electrodes

The potentials of various reference electrodes with respect to the normal hydrogen electrode are given in Table C.1 of Annex C.

5.4 Verification of reference electrodes

Reference electrodes used in the field shall be periodically checked with a master reference electrode having a valid calibration certificate. This master electrode shall be periodically (at least once a year) calibrated to a primary calibration reference electrode (N.H.E.).

Reference electrodes such as the saturated calomel electrode or various silver/silver chloride electrodes with different concentrations of KCl electrolyte may be used as master reference electrodes.

5.5 Potential measurement

Irrespective of the type of reference electrode used the measurement of the potential difference between the metal surface and the electrolyte can be affected by the potential drop produced by the protection current as it flows through the surrounding electrolyte to the structure. This effect, known as the IR drop, makes the measured potential more negative than the actual potential at the metal / electrolyte interface. The IR drop is dependent on electrolyte resistivity and is particularly relevant to buried structures.

IR drop errors are generally considered insignificant in marine applications especially when galvanic anodes are used. However potential measurements using “Instant Off” techniques or “coupon Instant Off” techniques (see EN 13509), or after switch-off of impressed current systems may be necessary in order to adequately demonstrate the achievement of the protection criteria, especially in brackish waters and close to impressed current anodes.

To determine the risks of overprotection (see 6.1) it is essential to measure the structure potential immediately after switching off the current source and before the metallic material depolarizes. This can be achieved with a fast sampling data logger or an oscilloscope.

If the measured potentials are fluctuating it may be due to either stray currents or telluric currents interference.

Documents
Document Sharing Hub
Full document details: BS EN 12473:2014