ABYC E-2 July, 2013

Electrical Division Standard

Electrical Project Technical Committee

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ABYC E-2

CATHODIC PROTECTION

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This standard, which is the result of extended and careful consideration of available knowledge and experience on the subject, is intended to provide minimum performance requirements.

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REQUEST FOR INTERPRETATIONS

Upon written request, the Electrical PTC will render an interpretation of any requirement of the Standard. The request for interpretation should be clear and unambiguous. Requests should be presented to the PTC in a manner in which they may be answered in a yes or no fashion.

The Committee reserves the right to reconsider any interpretation when or if additional information which might affect it becomes available to the PTC. Persons aggrieved by an interpretation may appeal to the Committee for reinterpretation.

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Based on ABYC's assessment of the existing technology, and the problems associated with achieving the goals of the standard, ABYC recommends compliance for systems and associated equipment manufactured and/or installed after July 31, 2014.

2.1 ***PURPOSE***

This standard is a guide for the design, installation, and use of cathodic protection systems on boats.

2.2 ***SCOPE***

This standard applies to the use of galvanic anodes and impressed current systems installed on boats.

2.3 ***REFERENCES***

The following publications form a part of this standard. Unless otherwise noted the latest version of referenced standards shall apply.

2.3.1 ABYC - American Boat & Yacht Council, Inc., 613 Third Street, Suite 10, Annapolis, MD 21403.
Phone: (410) 990-4460. Fax: (410) 990-4466. Website: www.abycinc.org.

A-28, *Galvanic Isolators*
E-11, *AC & DC Electrical Systems on Boats*
TE-4, *Lightning Protection*

2.4 ***DEFINITIONS***

For the purpose of this standard the following definitions apply:

2.4.1 Active-Passive Metals - Metals that exhibit two distinct corrosion potentials depending on the composition of the electrolyte, other environmental factors, and/or surface conditions of the metal itself. The austenitic (300-series) stainless steels are typical examples of active-passive metals.

2.4.2 Amphoteric - Capable of reacting chemically in an acid or a base. Certain oxides of a few metals, including aluminum, tin, lead, and zinc, are amphoteric, which renders those metals more susceptible to corrosion in alkaline electrolytes than other metals.

2.4.3 Anode (Galvanic Anode) -

2.4.3.1 An electrode of a simple electrochemical cell at which metal ions pass into the electrolyte and the metal wastes away.

2.4.3.2 An electrode of a galvanic cell which has a more negative corrosion potential than another electrode of the cell.

2.4.3.3 An electrode of a supplied-current cell which is connected to the positive terminal of a DC current source. See Cathode

2.4.4 Anode Reaction - A type of electrochemical reaction in which metal passes into an electrolyte as ions leaving behind electrons and thus increasing the number of excess free electrons in the solid metal. See Cathode Reaction

2.4.5 Anodic – Less Noble, having a relatively negative corrosion potential. Pertaining to an electrochemical anode reaction. See Cathodic

2.4.6 Anodic to - Having a more negative corrosion potential than. See Cathodic to

2.4.7 Anti-Fouling Coating – A coating applied to the hull and other underwater structures intended to prevent bio-fouling.

2.4.8 Barrier Coating – A coating applied to the wetted metal surfaces of the hull and other underwater metal structures that isolates the substrate from water, and reduces the current required to provide cathodic protection.

2.4.9 Calcareous Coating or Deposit - A film consisting primarily of calcium carbonate and magnesium hydroxide which may be deposited on the cathodes of electrochemical cells in sea water, and reduces the current required to provide cathodic protection.

2.4.10 Cathode –

2.4.10.1 An electrode of a simple electrochemical cell at which excess free electrons in the metal are neutralized by an electrochemical reaction.

2.4.10.2 An electrode of a galvanic cell which has a more positive corrosion potential than another electrode of the cell.

2.4.10.3 An electrode of a supplied-current cell which is connected to the negative terminal of a DC current source. See Anode

2.4.11 Cathode Reaction - A type of electrochemical reaction that consumes electrons and thus decreases the number of excess free electrons in the solid metal.

2.4.12 Cathodic – More Noble, having a relatively positive corrosion potential. Pertaining to an electrochemical cathode reaction. See Anodic

2.4.13 Cathodic Bonding - The electrical interconnection of metal objects in common contact with water, to the engine negative terminal, or its bus, and to the source of cathodic protection.

2.4.14 Cathodic Corrosion – Corrosion of certain metals (such as aluminum) caused by excessive cathodic protection.

2.4.15 Cathodic Disbondment – A loss of adhesion between a coating and its substrate caused by products of a cathode reaction.

2.4.16 Cathodic Protection - Reduction or prevention of corrosion of an immersed metal by making it a cathode of a galvanic or supplied-current (impressed-current) electrochemical cell.

2.4.17 Cathodic Protection Controller (Corrosion Controller) - An automatic or manually operated device, in a controlled cathodic protection system, to regulate the flow of cathodic protection current.

2.4.18 Cathodic to - Having a more positive corrosion potential than. See Anodic to

2.4.19 Cavitation - The formation and rapid collapse of vapor bubbles due to localized low pressure in liquids flowing over surfaces, resulting in physical impacts. This can cause a corrosion-like loss of metal.

2.4.20 Cell (Electrochemical Cell) - An electric circuit consisting of two or more electrodes which are in contact with a common body of electrolyte and which are also connected electrically by direct contact or by a metallic link.

2.4.21 Conductor - A material capable of carrying electric current as a flow of free electrons. See Electrolyte

2.4.22 Corrosion - The deterioration of or loss of metal by physical, chemical or electrochemical reactions.

2.4.23 Corrosion Potential – The potential of an isolated metal in an electrolyte, relative to a reference electrode. Also called rest potential, open circuit potential, freely corroding potential, and natural potential.

2.4.24 Couple - Two dissimilar metals or alloys in electrical contact with each other that have different potentials and become anodes or cathodes when in common contact with an electrolyte. A couple may also be formed on the surface of the same metal.

2.4.25 Crevice Corrosion - Corrosion of an active-passive metal caused by a breakdown of the passive film, which is initiated by a low oxygen concentration due to localized depletion of oxygen in restricted bodies of electrolyte.

2.4.26 Current Density - For corrosion purposes, the current per unit area of the anodes or cathodes expressed in milliamperes per square foot.

2.4.27 De-alloying - A corrosion phenomenon affecting certain alloys in which a less-noble alloy constituent leaches from the alloy. Dezincification of copper-zinc alloys (brasses) is the most common form of de-alloying seen in the marine environment.

2.4.28 Dielectric Shield - In a cathodic protection system, an electrically non-conductive material, such as a coating, or plastic sheet, that is placed around an anode to shield the hull from the effects of the strong electric fields at impressed current anodes, reentry and to improve current distribution to the cathode.

2.4.29 Dissimilar metals - Metals having different corrosion potentials, which therefore form a galvanic cell when electrically connected and in contact with a common body of electrolyte.

2.4.30 Driving Potential or Driving Voltage -

2.4.30.1 The open-circuit potential difference between the anodes and the cathodes of a simple or galvanic electrochemical cell.

2.4.30.2 The open-circuit potential of the external current source of a supplied-current cell.

2.4.31 Electric Current - The movement of electrons through metals or of ions through electrolytes.

2.4.32 Electrically Connected - Metallic objects in direct contact or connected by a metallic link, thus allowing electric current, as electrons, to flow between them.

2.4.33 Electrode - A conductive material, in an electrolyte, through which electrical current enters or leaves.

2.4.34 Electrolysis - The breakdown of an electrolyte resulting from current flowing in an electrochemical cell that includes that electrolyte. Example: the breakdown of water into hydrogen and oxygen gases in a supplied-current electrochemical cell.

NOTE: The term "Electrolysis" is often used loosely to describe corrosion in general, or the operation of supplied-current cells in particular. Its use in this respect is often confusing, and should be discouraged.

2.4.35 Electrolyte - A liquid (usually water) containing dissolved ions, capable of carrying electric current as the flow of those ions. See Conductor

2.4.36 Erosion-Corrosion - Corrosion that is induced by the flow of water over the surface of a metal.

2.4.37 Galvanic Cell - An electrochemical cell consisting of two or more metals having different corrosion potentials, electrically connected and in contact with a common body of electrolyte. See Supplied-Current Cell, Simple Electrochemical Corrosion Cell

2.4.38 Galvanic Corrosion - The corrosion that occurs at the anode(s) of a galvanic cell.

2.4.39 Galvanic Current - The electric current that flows between metals or conductive nonmetals in a galvanic cell.

2.4.40 Galvanic Isolator - A device installed in series with the grounding (green or green with yellow stripe) conductor of the shore power cable to block low voltage DC galvanic current flow, but permit the passage of alternating current (AC) normally associated with the (AC) grounding (green or green with yellow stripe) conductor.

2.4.41 Galvanic Series - A list of metals and alloys arranged in order of their corrosion potentials in a particular electrolyte relative to a reference electrode. The Galvanic Series of corrosion potentials is arranged with the negative, anodic, or least noble metals at one end, and the positive, cathodic, or most noble metals at the other. See TABLE **I**

2.4.42 Hull Potential - The composite potential of the electrically-connected immersed metal parts of a hull, relative to a reference cell.

2.4.43 Hull Potential Monitor - A device capable of measuring and displaying the potential difference between a reference electrode and a metal hull, or cathodic bonding system.

2.4.44 Impressed Current - Direct current supplied by a device employing a power source external to the electrode system of a cathodic protection installation.

2.4.45 Ion - An atom or a chemically bonded group of atoms, possessing a net electrical charge.

2.4.46 Ionic Current – Conduction of electrical current in an electrolyte by the movement of ions.

2.4.47 Mill Scale - The heavy oxide layer formed during hot fabrication or heat treatment of metals. Mill scale on steel is cathodic to the base metal.

2.4.48 Noble – Metals having corrosion potentials toward the positive end of the galvanic series.

2.4.49 Open-circuit Potential - The potential of an electrode measured with respect to a reference electrode or another electrode when no current flows to or from it.

2.4.50 Passive Film - A protective oxide film, formed either naturally or by chemical treatment, on certain active-passive metals like stainless steel alloys.

2.4.51 pH - A number indicating the concentration of hydrogen ions in a water solution. The pH scale runs from 0 (indicating acidity) through 7 (indicating neutrality) to 14 (indicating alkalinity).

2.4.52 Polarization –

2.4.52.1 A shift in the potential of an electrode of an electrochemical cell resulting from the flow of current in the cell.

2.4.52.2 A gradual reduction in the amount of current required to maintain a desired potential on a cathodically protected metal surface, resulting from the formation of surface films and/or local changes in electrolyte composition.

2.4.53 Reference Electrode - An electrode of known standard potential used for measuring the potentials of other electrodes in the same body of electrolyte. Commonly used to measure hull potentials and the potentials of other underwater metal structures. There are two basic types of reference electrodes. Metallic reference electrodes such as silver-silver chloride (Ag/AgCl) and zinc (Zn), and half-cell reference electrodes such as Saturated Calomel (SCE) and Copper-Copper Sulfate (Cu/CuSO4). Half-cell reference electrodes are not commonly used for working cathodic protection system measurement and control in natural waters.

2.4.54 Sacrificial Anode - A less noble metal intentionally electrically connected to, and in contact with the same body of electrolyte as a more noble metal, for the purpose of protecting the more noble metal from corrosion.

2.4.55 Shaft Contactor - A device intended to make electrical contact to a rotating shaft. (e.g. slip ring assemblies, shaft brushes, and shaft wipers)

2.4.56 Simple Corrosion Cell - An electrochemical cell in which the anodes and cathodes are located on the surface of a single metal object in contact with an electrolyte. See Galvanic Cell, Supplied-Current Cell

2.4.57 Slip Rings - One or more continuous conducting rings that mate to shaft brushes to provide electrical contact to rotating, or otherwise moving, shafts in order to improve electrical contact to the cathodic bonding system.

2.4.58 Stray-Current Corrosion - Corrosion resulting from an unintentional or accidental supplied-current DC or AC cell.

2.4.59 Substrate – The underlying base on which coatings are applied.

2.4.60 Supplied-Current Cell - An electrochemical cell in which an externally-driven current source is interposed in the circuit. Impressed-current cathodic protection and stray-current corrosion are both examples of supplied-current cells. See Galvanic Cell, Simple Corrosion Cell

2.5 ***GENERAL APPLICATION OF CATHODIC PROTECTION***

2.5.1 A cathodic protection system shall be capable of inducing and maintaining a minimum negative shift of 200 mV relative to the corrosion potential of the least noble metal being protected.

NOTES:
1. The negative potential (e.g., -1050 mV as compared to silver/silver chloride reference electrode) that can be achieved by some corrosion control systems will result in some decrease in effectiveness of anti-fouling paints. Because the decrease in effectiveness increases with higher negative voltages, the negative

potential should be kept as close to the optimum value as possible (see TABLE II). A reference potential reading in excess of -1100 mV indicates excessive cathodic protection.

2. The need for a cathodic protection system for metal appendages on non-metallic hulls may not be justified if the metals coupled are galvanically compatible (see TABLE II); however, individual testing on a case by case basis is necessary.

2.5.2 Hull-mounted metallic trim tabs

2.5.2.1 On boats equipped with aluminum drive systems, metallic trim tabs shall be installed in accordance with the manufacturer's instructions, and may be isolated from the boat's cathodic bonding system to reduce the load on the boat's cathodic protection system.

2.5.2.2 Metallic trim tabs shall be electrically isolated from their electrically actuated mechanisms, in accordance with ABYC E-11, *AC and DC Electrical Systems on Boats*.

2.5.2.3 If a metallic trim tab system is connected to a boat's cathodic bonding system, the cathodic protection system's output rating shall be increased to provide the additional required protection.

2.5.2.4 An effective method of cathodic protection shall be provided to all components of a metallic trim tab assembly.

2.5.3 Immersed cathodic metal surfaces shall be favorably matched in anode to cathode area relationship.

NOTE: Coating of cathodic metal surfaces may be used to achieve the relationship.

2.5.4 Coatings

2.5.4.1 If anti-fouling coatings containing pigments that are galvanically incompatible with the substrate metal are used, then cathodic protection shall be maintained and a barrier coating shall be used between the anti-fouling coating and the substrate.

NOTE: Prior to the application of a barrier coating on metallic surfaces, the surface should be tested for the presence of soluble salts. If salts are present on a surface, they should be reduced to an acceptable level of three micrograms per square centimeter prior to the application of a barrier coating. Special solutions for the reduction of soluble salts, as well as test kits are commercially available.

2.5.4.2 Coatings on surfaces shall be capable of tolerating alkali generated by the cathodic protection system.

2.5.5 Anode Placement

2.5.5.1 Anodes shall be mounted on a surface that cannot entrap gas bubbles.

2.5.5.2 Anodes shall be located so as not to disturb the flow of water past the propeller(s) or jet drive intake and nozzle(s).

2.5.5.3 Anodes shall be mounted so as not to disturb water flow near intakes and discharge fittings.

2.5.5.4 Sacrificial anodes and reference electrodes shall be installed to avoid areas marked for lifting slings and chocks.

2.5.6 All metals that are to receive cathodic protection from the cathodic protection system shall have a maximum resistance of one ohm to the cathodic bonding system anode.

NOTES:
1. An electrical resistance greater than one ohm will degrade cathodic protection system performance.

2. Propeller shafts do not provide reliable electrical continuity to the boat's cathodic bonding system.

3. Resistance measurements should only be taken when the boat is out of the water.

4. Hull potential measurements using a reference electrode should be used to determine cathodic bonding system integrity when the boat is in the water.

2.5.7 Rudderposts shall be cathodically bonded by means of a flexible conductor positioned to allow full rudder movement without stressing the cathodic bonding conductor or its connection.

2.5.8 Cathodic Bonding Conductors

2.5.8.1 Cathodic bonding conductors shall be oil resistant insulated, tinned, stranded copper wire, or uninsulated copper strip. Copper braid or copper tubing shall not be used for this purpose.

2.5.8.1.1 Uninsulated copper strip, metal mounting hardware, and terminal hardware shall not be in direct contact with wood.

2.5.8.1.2 Connections to the uninsulated copper strip shall comply with ABYC E-11, *AC and DC Electrical Systems on Boats.*

2.5.8.2 Wire, where used as a cathodic bonding conductor, shall be at least #8 AWG, or

2.5.8.2.1 where the cathodic bonding system is used as a part of the lightning protection system, this conductor shall not be less than the equivalent of #6 AWG. See ABYC TE-4*, Lightning Protection*

EXCEPTION: Wiring provided by engine and drive manufacturers contained on the engine/drive system.

2.5.8.3 Cathodic bonding conductors fabricated from a copper strip shall have a minimum thickness of 1/32 inch (0.8 mm) if connections are thru-bolted and a minimum width of 1/2 inch (13 mm), or

2.5.8.3.1 connections using machine screws shall have a minimum thickness sufficient to allow for the engagement of four threads at connections if drilled and tapped, and a minimum width of 1/2 inch (13mm).

2.5.8.4 Self tapping fasteners shall not be used at connections.

NOTE: These requirements are based on physical strength, the ability to make and maintain low resistance connections, and current ratings.

2.5.8.5 Insulated conductors shall be selected from ABYC E-11, *AC and DC Electrical Systems on Boats*.

2.5.8.6 Insulated conductors shall be identified by the color green or green with yellow stripe(s).

2.5.9 Shaft brushes used to provide cathodic protection shall be constructed of materials which will not score the shaft at the shaft-to-brush contactor.

2.5.10 A metal hull shall be connected directly to the engine negative terminal, and

2.5.10.1 the connection shall be made above the normal accumulation of bilge water, and

2.5.10.2 if a lightning protection system is installed on the boat, this conductor shall not be less than the equivalent of #6 AWG. See ABYC TE-4*, Lightning Protection*

2.6 ***GALVANIC ISOLATION***

2.6.1 If installed, galvanic isolators shall be installed in accordance with ABYC A-28, *Galvanic Isolators*.

2.6.2 If installed, isolation transformers shall be installed in accordance with ABYC E-11, *AC and DC Systems on Boats*.

NOTE: It is strongly recommended that any boat with a permanently installed shore power system be provided with galvanic isolation. Galvanic isolation may be achieved by use of a galvanic isolator, polarization transformer with galvanic isolator, or an isolation transformer. The electrical interconnection that occurs via shorepower grounding conductor may result in the flow of galvanic current between the boat and dock structure or another boat. This can lead to excessive anode loss, or corrosion beyond the capacity of the boat's cathodic protection system.

2.7 ***SACRIFICIAL ANODES***

2.7.1 If installed, the mass and exposed surface area of the anode(s) used to achieve cathodic protection (e.g., magnesium, zinc, aluminum,) shall be sufficient to provide continuous current output or capable of inducing and maintaining acceptable potential levels according to E-2.5.1 for at least the period between inspections.

NOTES:
1. Inspections may be conducted at intervals suitable for the usage and location of the boat, generally annually. See APPENDIX

2. Typical compositions of zinc, aluminum, and magnesium anodes appear in ABYC E-2 APPENDIX (see E-2 Ap.). Zinc anodes require zinc of high quality with the most undesirable (critical) trace element being iron. The addition of cadmium and aluminum will permit an increase in the tolerance for iron. Zinc anodes have a natural potential approximately -1050 mV with reference to a silver/silver chloride reference electrode in seawater.

3. The fixed potential of sacrificial anodes provides their basic utility, but the available current depends upon the exposed surface and the necessary mass to maintain this current over a period of time.

4. Anodes may be selected based upon location of the boat as follows:*

	Salt Water	Brackish Water	Fresh Water
Zn	√		
Al	√	√	√
Mg			√

****This table is not a substitute for testing in accordance with this standard.***

5. Sacrificial anodes may be mounted directly on the metal to be protected.

6. Zinc or aluminum galvanic anodes may be applied directly to aluminum, steel and non-metallic hulls without shielding.

2.7.2 Sacrificial anodes on a shaft shall be installed so as not to restrict water flow to strut bearings.

NOTE: Collars applied to the propeller shaft of boats are usually adequate to protect the propellers and shafts of bronze and stainless steel.

2.7.3 Magnesium hull anodes installed on steel or aluminum hulls shall have a dielectric shield installed between the anode and the hull.

2.7.4 Each anode shall have a single point of connection to the bonding system.

2.8 ***IMPRESSED CURRENT SYSTEMS***

2.8.1 If installed, the impressed current cathodic protection system installation shall be in accordance with the following:

2.8.1.1 If impressed current cathodic protection systems obtain power from the boat's battery system, provision shall be made to maintain battery charge.

2.8.1.2 All electrical connections to the AC or DC electrical system shall be in accordance with ABYC E-11, *AC and DC Electrical Systems on Boats*.

2.8.1.3 The cathodic protection controller of an impressed current system shall cut off, or reduce impressed current to a hull potential level not to exceed the maximum level in Table II, if the lead to the reference electrode is shorted to ground or broken.

2.8.1.4 Hull anodes, reference electrodes, and other components that penetrate the hull below the water line shall be designed, constructed, and installed so that they will not loosen or fail structurally when subjected to the stresses and conditions normally imposed on the hull.

2.8.1.5 Hull anodes shall be designed and installed to prevent electrical leakage from anode electrical connections to internal metallic parts of the assembly so as to minimize stray current corrosion through contact with bilge water.

2.8.1.6 Impressed current cathodic protection systems shall be used only on boats with negatively grounded or ungrounded electrical systems unless an independent source of power is provided that is negatively grounded.

2.8.1.7 System controllers shall be installed at least three feet (one meter) from compasses and other magnetically sensitive equipment. Associated wiring shall be either twisted pair or shielded when in proximity to such equipment.

2.8.1.8 Impressed current anodes shall be separated from a metal hull by an insulating barrier extending beyond the edge of the anode a distance in accordance with TABLE III. See FIGURE 1

EXCEPTION: Combination anode/reference electrode assemblies mounted directly to the drive system

2.8.1.9 The width of the dielectric shield above the anode shall be increased to a minimum width of four inches (102mm) to prevent chemical attack of the hull material and paint directly above an anode due to gas generation. See FIGURE 1

2.8.1.10 Impressed current anodes shall have the words "DO NOT PAINT" on a visible surface when installed.

NOTE: Anodes of any type are ineffective if painted.

2.8.1.11 All boats with impressed current systems shall have a Hull Potential Monitor.

2.9 ***CATHODIC PROTECTION OF ALUMINUM DRIVE UNITS AND OTHER METALLIC COMPONENTS MOUNTED ON NON-METALLIC HULLS***

2.9.1 Aluminum drive units shall have a protective paint coating that is tenacious, resistant to erosion and provides a high resistance barrier between the aluminum and water.

NOTE: Aluminum is an amphoteric metal, with a negative potential of over 1200 mV that can cause harmful overprotection such as alkali corrosion of aluminum and possible hydrogen blistering of paint, also known as cathodic disbondment.

2.9.1.1 Galvanically incompatible anti-fouling coatings, without a barrier coating, shall not be used.

2.9.2 Sterndrives, outboards, and other metallic components shall be protected with sacrificial anodes mounted on the aluminum lower units, and/or sacrificial anodes mounted on the hull and connected to the cathodic bonding system, and/or an impressed current system.

NOTES:
1. Aluminum lower units on sterndrive and outboard engines may require cathodic protection in addition to that supplied by the manufacturer when moored or used extensively in salt or brackish waters.

2. Cathodic protection supplied by the drive manufacturer may not be sufficient to provide protection to additional metallic components.

3. Boats equipped to use dockside power are subject to galvanic corrosion because the boat ground is electrically connected to the shore ground via the grounding conductor. An isolation transformer, a galvanic isolator, or polarization transformer with galvanic isolator in the grounding conductor may be used to reduce this problem. See ABYC E-11, AC and DC Electrical Systems on Boats

4. Magnesium anodes should not be used in salt water since their negative potential is 1600 to 1630 mV. Aluminum is an amphoteric metal, with a negative potential of over 1200 mV that can cause harmful overprotection which may result in cathodic corrosion of aluminum and possible hydrogen blistering of paint, also known as cathodic disbondment.

2.10 *CATHODIC PROTECTION OF ALUMINUM HULLS*

2.10.1 If aluminum hulls are painted, they shall have a protective paint coating that is tenacious, resistant to erosion, and which provides a high resistance barrier between the aluminum and water.

NOTE: Aluminum is an amphoteric metal, with a negative potential of over 1200 mV that can cause harmful overprotection such as alkali corrosion of aluminum and possible hydrogen blistering of paint, also known as cathodic disbondment.

2.10.2 Aluminum hulls, normally stored in the water shall be protected with sacrificial anodes and/or impressed current cathodic protection (ICCP) systems mounted on the hull or underwater gear.

NOTES:
1. Boats equipped to use dockside power are subject to galvanic corrosion because the boat ground is electrically connected to the shore ground via the grounding conductor. An isolation transformer, a galvanic isolator, or polarization transformer with galvanic isolator in the grounding conductor may be used to reduce this problem. See E-11, AC and DC Electrical Systems on Boats, and A-28, Galvanic Isolators

2. If magnesium anodes are used in salt water, the negative potential may exceed 1200 mV maximum recommended potential and create the conditions for cathodic corrosion.

2.10.3 When practical, underwater fittings, propeller shafts, propellers, and rudders fabricated of bronze, or other metal alloys more noble than aluminum, shall be electrically insulated from metallic contact with the hull and from internal metallic piping.

NOTE: Shafts or rudders may be cathodically protected separately by anodes directly attached to the metal that is to be protected.

2.10.4 Fasteners used for connections to aluminum hulls shall be 300 series stainless steel.

2.10.5 The hull shall not be used as a current carrying conductor. See ABYC E-11, *AC and DC Electrical Systems*

2.11 *CATHODIC PROTECTION OF STEEL HULLS*

2.11.1 Steel hulls shall have a protective paint coating that is tenacious, resistant to erosion, and which provides a high resistance barrier between the steel and the water.

2.11.2 Steel hulls, normally stored in the water shall be protected with sacrificial anodes mounted on the hull, or sacrificial anodes mounted on underwater gear, or an impressed current system.

NOTE: Boats equipped to use dockside AC electric power are subject to galvanic corrosion because the boat ground is electrically connected to the shore ground via the grounding conductor. An isolation transformer, a galvanic isolator, or polarization transformer with galvanic isolator in the grounding conductor may be used to reduce this problem (see ABYC E-11, AC and DC Electrical Systems on Boats, and ABYC A-28, Galvanic Isolators).

2.11.3 When practical, underwater fittings, propeller shafts, propellers, and rudders fabricated of bronze, or other metal alloys more noble than steel, shall be electrically insulated from metallic contact with the hull, and from internal metallic piping.

NOTE: Shafts or rudders may be cathodically protected separately by anodes directly attached to the metal that is to be protected.

2.12 *HULL POTENTIAL MONITOR*

2.12.1 A Hull Potential Monitor shall have an internal resistance of not less than 20,000 ohms per volt, and be capable of measuring the voltage differences between a reference electrode, and a metal hull or the underwater metal components connected to the boats bonding system.

2.12.2 All vessels utilizing impressed current systems shall have a hull potential monitor and reference electrode permanently installed

NOTE: A hull potential monitor should be considered for any boat that remains in the water for extended periods.

TABLE I - GALVANIC SERIES OF METALS IN SEA WATER WITH REFERENCE TO SILVER/SILVER CHLORIDE REFERENCE CELL [Sea water flowing at 8 to 13 ft./sec. (except as noted), temperature range 50°F (10°C) to 80°F (26.7°C)]

(ANODIC OR LEAST NOBLE)	CORROSION-POTENTIAL RANGE IN MILLIVOLTS
Magnesium and Magnesium Alloys	-1600 to –1630
Zinc	-980 to –1030
Aluminum Alloys	-760 to –1000
Cadmium	-700 to –730
Mild Steel	-600 to –710
Wrought Iron	-600 to –710
Cast Iron	-600 to –710
13% Chromium Stainless Steel, Type 410 (active in still water)	-460 to –580
18-8 Stainless Steel, Type 304 (active in still water)	-460 to –580
Ni-Resist	-460 to –580
18-8, 3% Mo Stainless Steel, Type 316 (active in still water)	-430 to –540
Inconel (78%Ni, 13.5%Cr, 6%Fe) (active in still water)	-350 to -460
Aluminum Bronze (92% Cu, 8% Al)	-310 to -420
Nibral (81.2% Cu, 4% Fe, 4.5% Ni, 9% Al, 1.3% Mg)	-310 to –420
Naval Brass (60% Cu, 39% Zn)	-300 to –400
Yellow Brass (65% Cu, 35% Zn)	-300 to –400
Red Brass (85% Cu, 15% Zn)	-300 to –400
Muntz Metal (60% Cu, 40% Zn)	-300 to –400
Tin	-310 to –330
Copper	-300 to –570
50-50 Lead- Tin Solder	-280 to –370
Admiralty Brass (71% Cu, 28% Zn, 1% Sn)	-280 to –360
Aluminum Brass (76% Cu, 22% Zn, 2% Al)	-280 to –360
Manganese Bronze (58.8% Cu,39%Zn,1%Sn, 1%Fe, 0.3%Mn)	-270 to –340
Silicone Bronze (96% Cu Max, 0.80% Fe, 1.50%Zn, 2.00% Si, 0.75% Mn, 1.60% Sn)	-260 to –290
Bronze-Composition G (88% Cu, 2% Zn, 10% Sn)	-240 to –310
Bronze ASTM B62 (thru-hull)(85%Cu, 5%Pb, 5%Sn, 5%Zn)	-240 to –310
Bronze Composition M (88% Cu, 3% Zn, 6.5% Sn, 1.5% Pb)	-240 to –310
13% Chromium Stainless Steel, Type 410 (passive)	-260 to –350
Copper Nickel (90% Cu, 10% Ni)	-210 to –280
Copper Nickel (75% Cu, 20% Ni, 5% Zn)	-190 to –250
Lead	-190 to –250
Copper Nickel (70% Cu, 30% Ni)	-180 to –230
Inconell (78% Ni, 13.5% Cr, 6% Fe) (passive)	-140 to –170
Nickel 200	-100 to –200
18-8 Stainless Steel, Type 304 (passive)	-50 to –100
Monel 400, K-500 (70% Ni, 30% Cu)	-40 to –140
Stainless Steel Propeller Shaft (ASTM 630:#17 & ASTM 564: # 19)	-30 to +130
18-8 Stainless Steel, Type 316 (passive) 3% Mo	0.0 to –100
Titanium	-50 to +60
Hastelloy C	-30 to +80
Stainless Steel Shafting (Bar) (UNS 20910)	-250 to +60
Platimium	+190 to +250
Graphite	+200 to +300
(CATHODIC OR MOST NOBLE)	

†The range shown does not include sacrificial aluminum anodes. Aluminum alloy sacrificial anodes are available that have a maximum corrosion potential of -1100 mV.

NOTES:

1. Metals and metal alloys are listed in the order of their potential in flowing sea water as determined in tests conducted by a nationally-recognized corrosion research laboratory.

2. The galvanic series may be used to predict whether galvanic actions are likely between two metals. Other factors (e.g., area of the material, flow rate, composition of the electrolyte, crevices, the coupling of copper alloys with aluminum, etc.) affect the relative corrosion rates in seawater. See ***Ap. 4 & Ap. 5***

TABLE II - RECOMMENDED RANGE OF CATHODIC PROTECTION BASED ON AG/AGCL REFERENCE CELL

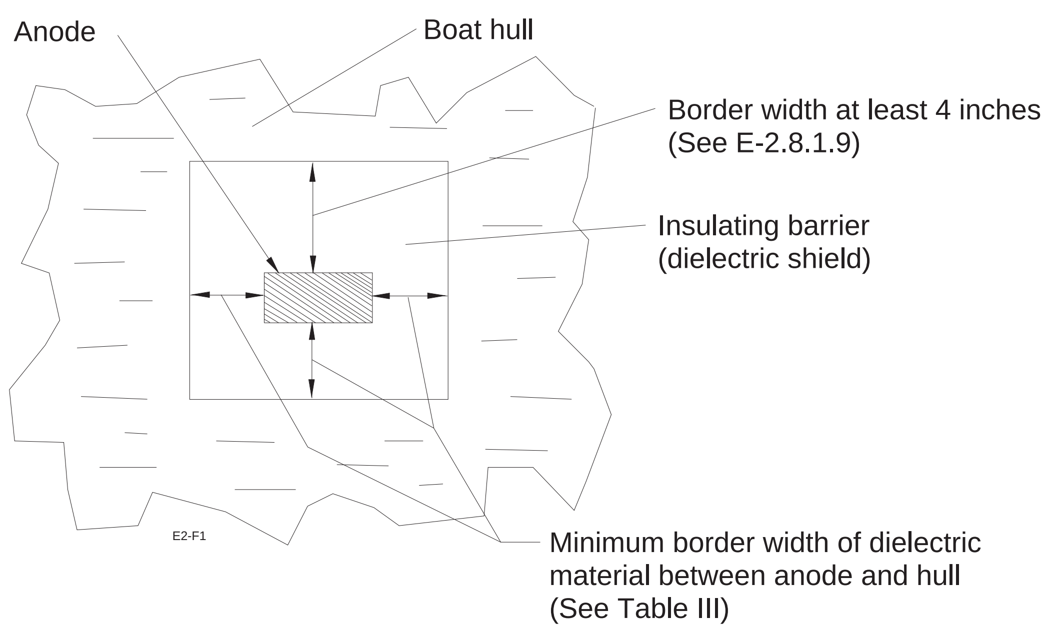
HULL MATERIAL	MILLIVOLT RANGE
Fiberglass	-550 to –1100
Wood	-550 to –600
Aluminum	-950 to –1100
Steel	-850 to –1100
Non-metallic w/Aluminum Drives	-950 to -1100

NOTE: Exceeding -600mV on a wooden boat may lead to significant damage to wetted wood surfaces in contact with the cathode.

TABLE III – SHIELDING OF IMPRESSED CURRENT ANODES

Maximum Current Output of Anode	Minimum Border Width of Dielectric Material between Anode and Metal Hulls
Milliampere	Inches
Below 350	1/2 (13 mm)
350-1500	3 (77 mm)
1501-5000	8 (205 mm)

FIGURE 1 - DIELECTRIC SHIELDING FOR IMPRESSED CURRENT ANODE



APPENDIX

Ap.1 Typical compositions of anodes are provided in the tables below.

Ap.2 In general, the use of several anodes in parallel, instead of one large anode, tends to provide better distribution of the protective current.

NOTE: The best current distribution will be obtained by remote mounting with the anode(s) positioned to be as equidistant as possible from the metals to be protected.

Ap.3 ***IMPRESSED CURRENT PROTECTION - APPLICATION***

Ap.3.1 Impressed current cathodic protection devices are electronically controlled and should be used where cathodic protection is needed and where it is desired to eliminate the use of, or extend the life of, sacrificial anodes.

Ap.3.2 The devices use an external voltage source and an anode with a control to adjust the amount of current in the circuit. All the systems have automatic adjustment that senses the reference electrode voltage and automatically supplies the right amount of current to the anode to maintain the protection required. The controllers for larger systems may have adjustable set points.

Ap.4 ***FACTORS THAT AFFECT THE TYPE AND DEGREE OF CATHODIC PROTECTION REQUIRED***

Ap.4.1 Water Velocity - Cathodic protection current requirements increase with water velocity past the hull. The current requirement can be several times that required in still water. Uncontrolled sacrificial anodes do not have the capability to increase current output as water velocity increases.

Ap.4.2 Boat Usage - More frequently operated vessels require more cathodic protection than vessels infrequently used.

Ap.4.3 Conductivity of the Water - As the conductivity increases, the rate of galvanic activity increases.

Ap.4.4 Salinity (Fresh and Seawater) - Current requirements increase with salinity but higher driving potentials are required in fresh water.

Ap.4.5 pH of the Water - As pH decreases (acid rain lakes), the corrosion rate increases.

Ap.4.6 Deterioration of Protective Coatings - Current requirements increase as protective coatings deteriorate increasing exposed cathode surface area.

Ap.5 ***FACTORS THAT AFFECT THE LONGEVITY AND ADEQUACY OF ANODES AND SYSTEM EQUIPMENT***

Ap.5.1 Paint - Painted areas of anodes will not produce electrical current.

Ap.5.2 Loose Connections - Loose anode attachments or loose/corroded electrical connections will reduce or eliminate electrical current flow from the anode.

Ap.5.3 Corrosion - Corrosion at the point where the anode is bolted to the structure to be protected can inhibit electrical current flow. The use of a more noble core material in the anodes will assist in controlling this problem.

Ap.5.4 Copper alloy electrical terminations, even if plated, shall not be in direct contact with aluminum.

NOTE: When bolting plated copper electrical terminals to aluminum, use a conductive anti-oxidizing aluminum paste formulated for aluminum/copper junctions. This paste is available from most commercial electrical supply houses.

Ap.5.5 Insufficient Mass/Surface Area - An anode that has sufficient surface area to produce the desired voltage initially, may not have enough weight to sustain the current output for the duration of the time that the vessel remains in the water (ie. time between haul-outs).

Ap.5.6 Impurities - Impurities in the zinc anode alloy such as iron can seriously reduce or terminate their electrical current output.

Ap.5.7 Improper Anode Contact - Metal foil anti-fouling systems must not come in contact with metals that are cathodically protected. This will render the anti-fouling properties of the foil useless, drastically reduce the protective voltage, cause rapid consumption of the anode, and lead to accelerated corrosion of normally protected metals.

Ap.5.8 Anode Composition - There are numerous anode compositions available. To insure the best performance, customers should specify military specification anodes for zinc, aluminum, and magnesium.

Ap. TABLE I - TYPICAL COMPOSITION OF ANODES

Ap. TABLE I-A - TYPICAL COMPOSITION OF ZINC ANODES IN PERCENTAGES OR RANGE

	ASTM B418		MIL-A-18001	Minimum Purity
	Type I	Type II		
Aluminum	.1 - .4	.005 max.	.1 - .5	3.9 - 4.3
Cadmium	.03 - .1	.003 max.	.025 - .15	.002 max.
Copper	-	-	.005 max.	.1 max.
Iron	.005 max.	.0014 max.	.005 max.	.05 max.
Lead	.003 max.	.003 max.	.006 max.	.002 max.
Magnesium	-	-	-	.005 - .02
Nickel	-	-	-	.005 - .02
Silicon	-	-	.125 max.	-
Tin	.001 max.	.001 max.	- -	.001 max.
Zinc (remainder)	99.5 min	99.99 min	99.2 min	95.5 min

Ap. TABLE I-B - TYPICAL COMPOSITION OF ALUMINUM ANODES IN PERCENTAGES OR RANGE (B605 ALLOY)

Zinc (range)	5.0 - 6.0 %
Iron (maximum)	0.17 %
Copper (maximum)	0.02 %
Silicon (maximum)	0.10 %
Aluminum	Remainder

Ap. TABLE I-C - TYPICAL COMPOSITION OF MAGNESIUM ANODE IN PERCENTAGES OR RANGE (MIL-A-21412)

Aluminum (range)	5.0 - 7.0 %
Zinc (range)	2.0 - 4.0 %
Manganese (minimum)	0.15 %
Silicon (maximum)	0.30 %
Copper (maximum)	0.10 %
Iron (maximum)	0.003 %
Nickel (maximum)	0.003 %
Other (maximum)	0.30 %
Magnesium	Remainder

Ap. TABLE II - CORRECTION FACTORS FOR REFERENCE ELECTRODES

Potential values of reference electrodes referred to Standard Hydrogen Electrode (S.H.E.), the standard to which other more convenient references are related:

HALF-CELL		POTENTIAL VOLT
Tenth Normal Calomel	TNCE	+0.333
Copper-Copper Sulfate	Cu/CuSO4	+0.316
Normal Calomel	NCE	+0.280
Saturated Calomel	SCE	+0.241
Silver/Silver Chloride	Ag/AgCl	+0.222
Standard Hydrogen Electrode	S.H.E.	0.000
Zinc	Zn	-0.778

Ap. TABLE III - REFERENCE/SENSING ELECTRODES POTENTIAL

Potential values of reference electrodes in seawater compared to:

Cu/CuSO4	Ag/AgCl	SCE	S.H.E.	Zn
+0.2	+0.3	+0.28	+0.52	+1.3
+0.1	+0.2	+0.18	+0.42	+1.2
0.0	+0.1	+0.08	+0.32	+1.1
-0.1	0.0	-0.02	+0.222	+1.0
-0.2	-0.1	-0.12	+0.12	+0.9
-0.3	-0.2	-0.22	+0.02	+0.8
-0.4	-0.3	-0.32	-0.08	+0.7
-0.5	-0.4	-0.42	-0.18	+0.6
-0.6	-0.5	-0.52	-0.28	+0.5
-0.7	-0.6	-0.62	-0.38	+0.4
-0.8	-0.7	-0.72	-0.48	+0.3
-0.9	-0.8	-0.82	-0.58	+0.2
-1.0	-0.9	-0.92	-0.68	+0.1
-1.1	-1.0	-1.02	-0.78	0.0
-1.2	-1.1	-1.12	-0.88	-0.1
-1.3	-1.2	-1.22	-0.98	-0.2
-1.4	-1.3	-1.32	-1.08	-0.3
-1.5	-1.4	-1.42	-1.18	-0.4
-1.6	-1.5	-1.52	-1.28	-0.5
-1.7	-1.6	-1.62	-1.38	-0.6
-1.8	-1.7	-1.72	-1.48	-0.7
-1.9	-1.8	-1.82	-1.58	-0.8
-2.0	-1.9	-1.92	-1.68	-0.9
-2.1	-2.0	-2.02	-1.78	-1.0

Converting Reference Electrode Values (Example)
-0.700 volts Ag/AgC1
+0.222 conversion factor
- 0.478 volts S.H.E.

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Origin and Development of ABYC E-2, Cathodic Protection.

E-2 was first published in 1965 with revisions in 1971, 1973, 1981, 1996, 2001 and 2008. The July 2013 revision is the work of the Electrical Project Technical Committee.

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