Cathodic protection for boats in saltwater

Marine corrosion has been a problem ever since boatbuilders started using metals on boats. When electricity came aboard, the problem grew even worse. Many marine publications have carried articles on the various causes of underwater corrosion and on that often confusing term, electrolysis. Nevertheless, the OSU Extension Service' Sea Grant marine advisory staff continues to receive requests concerning the causes and prevention of underwater corrosion: How much zinc is needed to protect a boat? What other types of cathodic protection can a mariner use? How does corrosion relate to faulty marine wiring? And so on.

To obtain reliable answers to such questions, despite the seemingly unlimited number of variable conditions involved, the authors worked with other members of the marine advisory staff to organize technical workshops investigating what successful marine service sources are, in fact, practicing. These workshops—Marine Technical Institutes—were held in Coos Bay and in Astoria.

This bulletin is a dividend of the experience and common practice examined during the institutes. It summarizes practical technical literature and documents opinions of industry specialists and boat owners with substantial experience under a range of working conditions. The findings apply primarily to working watercraft.

Recognize that the subject is very complex because adequate cathodic protection measures quite often are destroyed by faulty marine wiring. The intent of this bulletin is to offer clear information on how to protect your boat cathodically, assuming its marine electrical system is healthy. (The glossary, page 8, defines each term that appears in italics.)

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Corrosion is one of the biggest maintenance problems in vessels of all sizes, particularly in saltwater. It costs money, and it can cost lives if critical equipment weakened by corrosion is not replaced or repaired in time (figure 1).

Corrosion above the water line is one thing; your only defense there is frequent inspection and careful attention to painting, cleaning, and greasing. Corrosion of hull fittings and metals below the water line, however, is another matter. This you can control by *cathodic protection*, and this bulletin describes how you can achieve adequate protection, using either *zinc sacrificial anodes* or *impressed current systems.*

Corrosion is an electrochemical process in which a chemical reaction takes place, creating a flow of electrical charge, or *current*, between two unlike metals. This chemical action between two unlike metals can destroy one of the metals. When that metal is a propeller, strut, or shaft, the damage can grow expensive.

One cannot understand or design an adequate cathodic protection system without a basic knowledge of direct-current (d.c.) electrical theory. Ohm's Law is a handy starting point: Briefly, it states that current (I) in a circuit is proportional to the *potential* difference (E) across a circuit. The more *resistance* (R) in that circuit, the less the amount of current. Ohm's Law can be written mathematically as

$$\text{Current (amps)} = \frac{\text{potential (volts)}}{\text{resistance (ohms)}},$$

or

$$I = \frac{E}{R}.$$

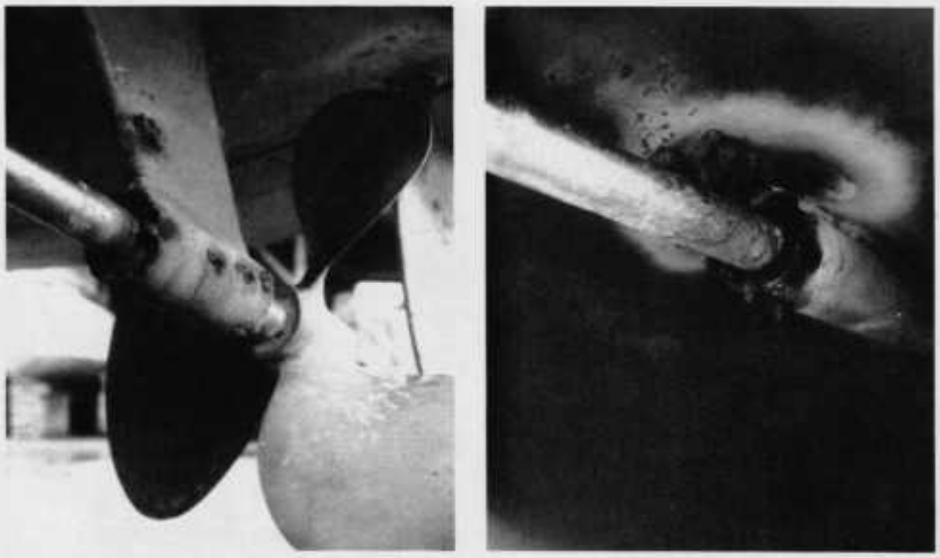


Figure 1.—*Severe stray-current corrosion caused this kind of damage to a steel power cruiser. Quick action saved this vessel from sinking because of hull perforation.*

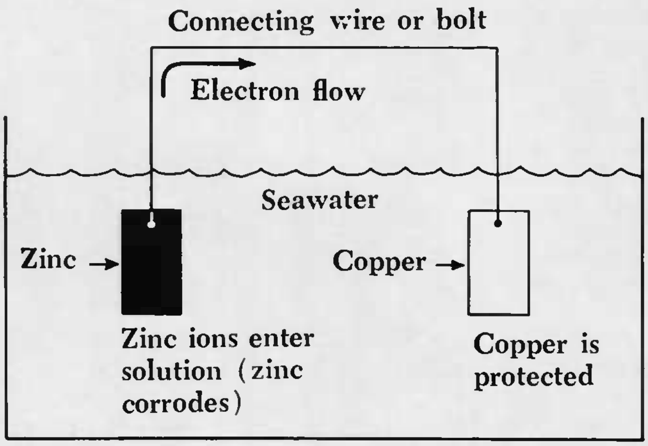


Figure 2a.—*Current will flow between two different metals in seawater that are connected together electrically.*

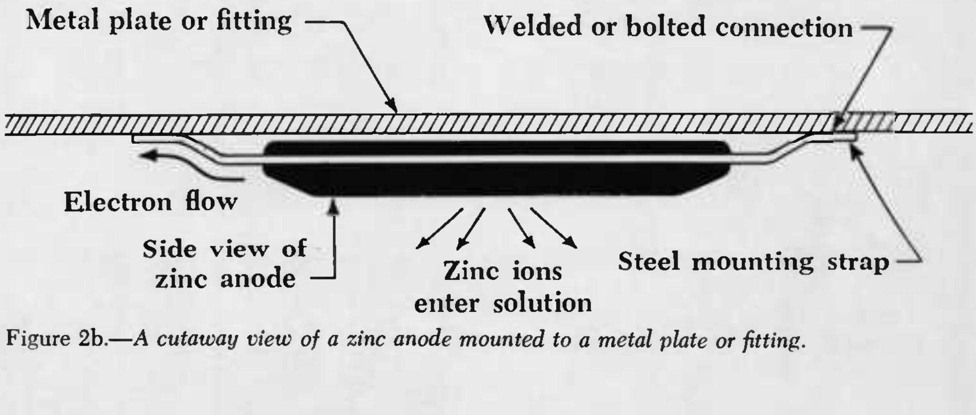


Figure 2b.—*A cutaway view of a zinc anode mounted to a metal plate or fitting.*

In other words, given a certain voltage, the lower the resistance, the greater the current; the higher the resistance, the smaller the current. The units of electrical characteristics—current, potential (another name for voltage), and resistance—are defined as follows. One ampere of current will flow through a 1-ohm resistance when a potential of 1 volt is impressed across the resistance. All electrical conductors have resistance.

Voltage is often compared to water pressure. Then, the water flowing under pressure through a pipe behaves like electricity. The amount of water moving through the pipe is analagous to the current. The frictional resistance to water flow within the pipe is the counterpart of the electrical resistance. Most of the discussion that follows relates to factors on and around boats in saltwater (and to a less severe extent, to those in freshwater) that can reduce the unwanted current that causes corrosion.

Types of corrosion

The simplest kind of corrosion to understand and prevent is called *galvanic action;* it occurs any time two different metals are connected together electrically and immersed in an electrolytic solution such as seawater. (Salt dissolved in water is an *electrolyte;* it makes the solution a *conductor* of electricity.)

Figure 2a shows an electrical diagram of galvanic action—a battery of sorts. Figure 2b shows how this action occurs on your boat. All metals tend to corrode, but some do so more actively than others —zinc, very much more so. In the example, zinc is corroding and protecting the copper by providing *electrons* through the connecting wire to the copper and preventing the loss of electrons from copper.

The zinc installed to protect copper fittings is said to be a "sacrificial anode." Thus, a piece of zinc that is attached to the boat corrodes before the structural components do. Another way to achieve protection is with an external source, such as the boat's battery, that may also supply electrons to the protected metal; this method is the basis for the impressed-current cathodic protection devices. (See "Controlled voltage systems.")

A second kind of corrosion, *stray-current corrosion,* is often the culprit when severe damage of underwater metals takes place. In fact, according to several marine electricians, stray currents cause 90% of underwater corrosion problems. This kind of corrosion can arise from many sources, including faulty or inadequate wiring, either on the boat or in the shore power connection.

All forms of underwater corrosion are often referred to as "electrolysis," but this label is widely misused. From a troubleshooting point of view, it is important to understand the difference between galvanic action and stray-current corrosion. The next sections describe how you can protect your vessel from both forms.

Preventing galvanic action

The commonest defense is the use of zinc sacrificial anodes. The determination of how many zincs to use, and of what size, seems to be more an art than a science. Many marine electricians decide how much zinc to install by measuring the potential of the hull relative to a *reference electrode* hung over the side. (Many skippers permanently mount reference electrodes and monitor meters on their vessels.)

Hull-potential measurement provides a fairly scientific way to "zinc" a boat. In this method, you simply add zincs to the boat until the hull potential reaches the desired value: for steel, about –0.85 volt versus a silver-silver chloride reference electrode. The optimum potentials for copper and aluminum are about –0.65 and –0.95 volt, respectively.

Another method is to install zinc anodes, then inspect to see if you installed enough when you haul your vessel out of the water after a year. If the anodes are 50 to 80% consumed, you have probably used the right amount. The best summary of common practice that the authors have been able to assemble appears as table 1; it reflects the amounts of zinc that representative working boats are using and knowledgeable service sources are recommending.

The table presents a consensus of recommended amounts of zinc for seven typical boat sizes, based on technical literature and on the experiences of marine electricians, boatyards, and users. These recommendations assume that the larger boats have more underwater hardware than smaller boats, such as radio ground plates and keel coolers. Note, too, that calculations of values for table 1 are for a boat underway, rather than sitting at the dock. The resulting higher values apply more to work boats than to pleasure boats.

Table 1.—*Pounds of zinc recommended for boats underway (water velocity of 5 knots or greater)**

Hull material	22-ft Dory or cruiser, OB or I/OB	32-ft Inboard troller	32-ft Aux. sailboat	40-ft Troller	48-ft Troller or combination boat	58-ft Combination boat	78-ft Dragger
Wood or fiberglass	2-4	18-28	4-7	40-60	50-75	65-100	105-160
Steel or ferrocement	20-30	70-105	45-65	110-165	160-235	230-345	405-610
Aluminum	0-15	30-45	10-20	55-80	80-120	120-185	225-340

* For the larger boats, this assumes use of 11.5-lb. rectangular anodes. Coverage assumes typical conditions of speed, paint condition after 1 year, salinity, and no electrical problems. For inboard vessels it also assumes copper alloy prop, ground plate, and keel cooler.

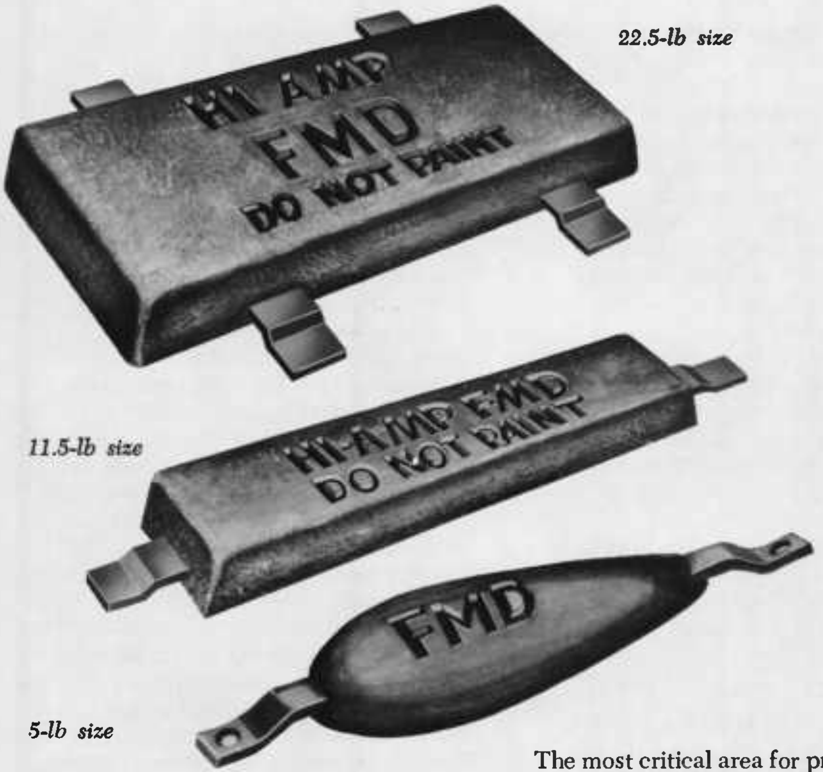


Figure 3.—*Typical zinc anodes (photos courtesy of Federal Metals Corporation).*

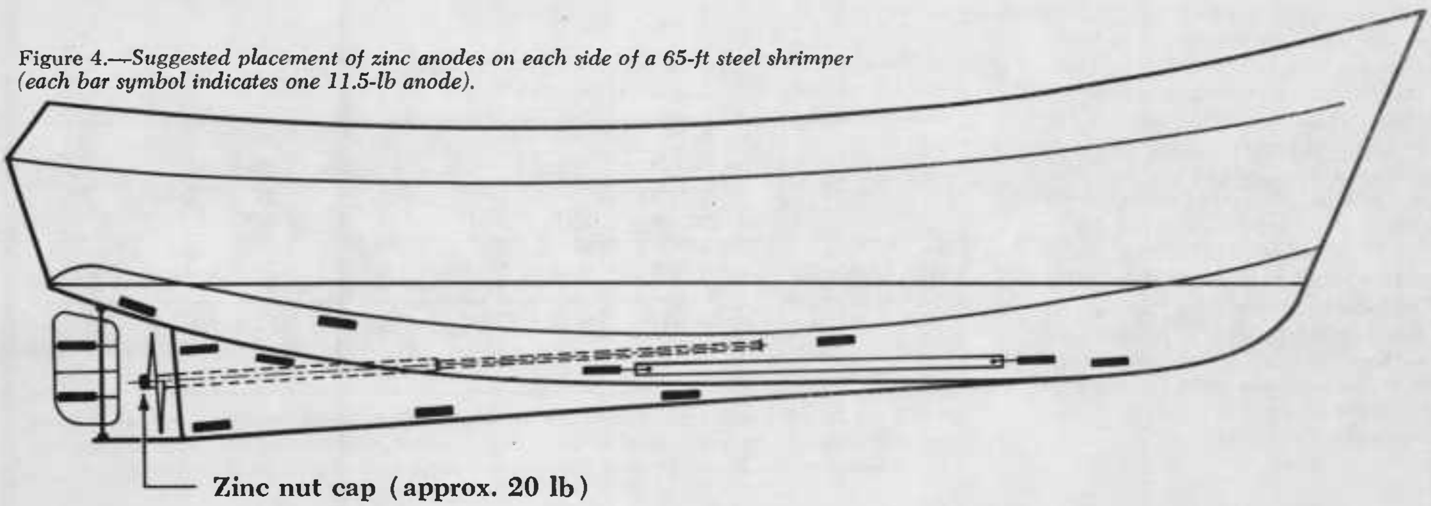
The type, size, and mounting procedure for zinc anodes are important. Figure 3 shows some typical zinc anodes manufactured by Federated Metals Corporation. The 11.5- and 22.5-pound (5.2- and 10.2-kilogram) sizes are commonly used on larger boats, and the 5-pound (2.2-kilogram) and smaller anodes are often seen on smaller boats such as wooden trollers.

The most critical area for protection on most boats is the propeller and shaft, so it is natural that skippers usually concentrate zincs in a vessel's stern. The use of a zinc wheel nut cap or shaft collar is common practice, and electrical specialists highly recommend it. In addition, anodes are needed on metal rudders, bow irons, keel shoes, and any other underwater metal fittings. Figure 4 shows recommended placement for zinc anodes on a typical 65-foot (20-meter) steel boat.

It is important that anodes have a good electrical connection to the metal they are protecting. For this reason, the best mounting systems use steel straps imbedded in ("cast-in") the anode. You then weld or bolt these straps to the boat or fitting to be protected. Figure 5 shows what can happen if you use zinc anodes without such cast straps.

Bolt-on connections require a good, tight contact; sand the mating surfaces with emery cloth until bright metal shows before you bolt them together, then seal the connections against seawater after you tighten them.

Figure 4.—*Suggested placement of zinc anodes on each side of a 65-ft steel shrimper (each bar symbol indicates one 11.5-lb anode).*



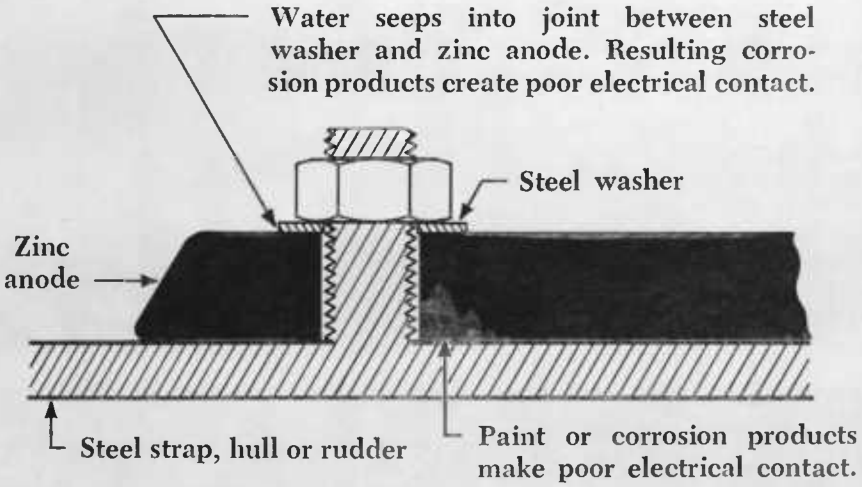


Figure 5.—*This is what happens if your zinc anodes have no cast-in straps or inserts.*

Factors influencing the proper amount of zinc

There are a lot of ifs, ands, and buts in the use of zinc. Remember that the "correct" amount of zinc can vary greatly, depending on your particular boat, where and how you use it, and other factors.

Overprotection. Unfortunately, it is possible to "overprotect" a boat—to use too much zinc on it—and actually cause damage to the hulls of wooden or aluminum boats. Overprotection can endanger oil-based paint, too—even on a steel boat. Modern steel boats with epoxy or vinyl paint systems are relatively immune to overprotection, but paint bubbling can occur even with them under some conditions.

The cause of this overprotection is the hydroxide ions (the active ingredient in caustic soda or lye) produced by the electrochemical reaction on the surface of the protected metal. These hydroxide ions chemically attack wood, aluminum, and oils.

Attack on wood is sometimes called "wood electrolysis" and may show inside the hull as a powdery substance near through-hull fittings and other protected metals. If you suspect that wood electrolysis is taking place, taste a small quantity of the deposit. If it tastes salty, you are simply getting salt buildup because of a leak. If it tastes bitter, however, you are tasting lye—and you probably have an overprotection situation. You can remove lye deposits by washing with distilled white vinegar, but you need to deal with the cause of the problem—too much zinc—immediately. Aluminum is also attacked by hydroxide ions, as pitting of hulls underwater has demonstrated.

For these reasons, it is a good idea to have a marine electrician measure your hull potential, especially if you have a wooden or aluminum boat. Hull-potential monitoring is probably your best insurance against both galvanic and stray-current corrosion. In fact, most experts recommend installing a permanent hull-potential monitoring meter and reference electrode.

For a small outlay of money, you can buy portable equipment to measure hull potential, but it is usually a better idea to have this service performed occasionally by an experienced marine electrician or electronics expert. Most active harbors have at least one person available who can make this kind of measurement.

Paint system. The condition of the paint will greatly affect the amount of cathodic protection current your boat needs. A steel hull with a good paint job needs far less zinc than one with old, badly worn paint and bare spots. Users of impressed-current devices with ammeters see this effect: As the season progresses and the paint wears, the current drawn by the system steadily increases; at haul-out time it can be several times greater than at launching.

Water-flow velocity. Much more current is drawn from the zincs when your vessel is underway than when it is moored (unless an a.c. stray-current problem exists; see "Stray current corrosion"). In fact, most of the experts recommend smaller amounts of zinc for still water than for moving water. The amounts needed differ by anywhere from two to six times. In still water, the products of the electrochemical reactions build up at the surfaces of the anode and underwater metals and lower the voltage of the galvanic "battery." As Ohm's Law explains, the current is reduced.

Moving water rinses off the surface products of the electrode reactions and keeps the voltage of the galvanic combination high. Then, as Ohm's Law shows, the current is also higher. Vessels that spend most of their time at sea or moored in tidal flow areas need more zinc than ones that spend most of their time in still water.

Water salinity. Salinity affects the need for cathodic protection; boats in saltwater need a great deal more zinc than boats in freshwater or brackish water. (The resistance of freshwater is much higher; therefore, the current flowing for the same potential is lower.)

Purity of the anode metal. Zinc anode material with more than about 0.005% iron tends to form a scale over its surface. Thus it corrodes poorly and provides very little protection to a boat. Melting down old zinc anodes and casting new ones presents a risk of introducing iron contamination. Some remelted anodes work well; others do not. To be completely safe, specify anodes conforming to military specification MIL-A-18001 H. Figure 6 shows what a properly corroding zinc anode looks like.

Magnesium anodes are also available, but magnesium is generally unsuitable for marine use; the voltage it produces in reaction with the protected metal is too high—usually causing overprotection. Special aluminum alloys have recently come into use as anode materials; however, for applications on small vessels they are not widely available, and they have not yet been proven in service, as have zinc anodes. Some aluminum anodes contain mercury, and the manufacturers caution against their use in estuaries or inshore operations.

Bonding of boats. One final note about zincs: You can achieve greater flexibility by bonding—tying together electrically all of the underwater parts of your boat, using a heavy copper conductor (see figure 7). Bonding is recommended for all boats for a number of reasons, not the least of which is suppression of radio noise.

Bonding allows one zinc anode to protect several fittings, as long as the anode is of sufficient size. The only really tricky job is bonding the propeller and shaft: The film of oil on the gears in the gearbox acts as an *insulator*. You can solve this problem by using a shaft brush, or you can leave the propeller/shaft combination unbonded and protect it separately with a zinc nut cap or shaft collar.

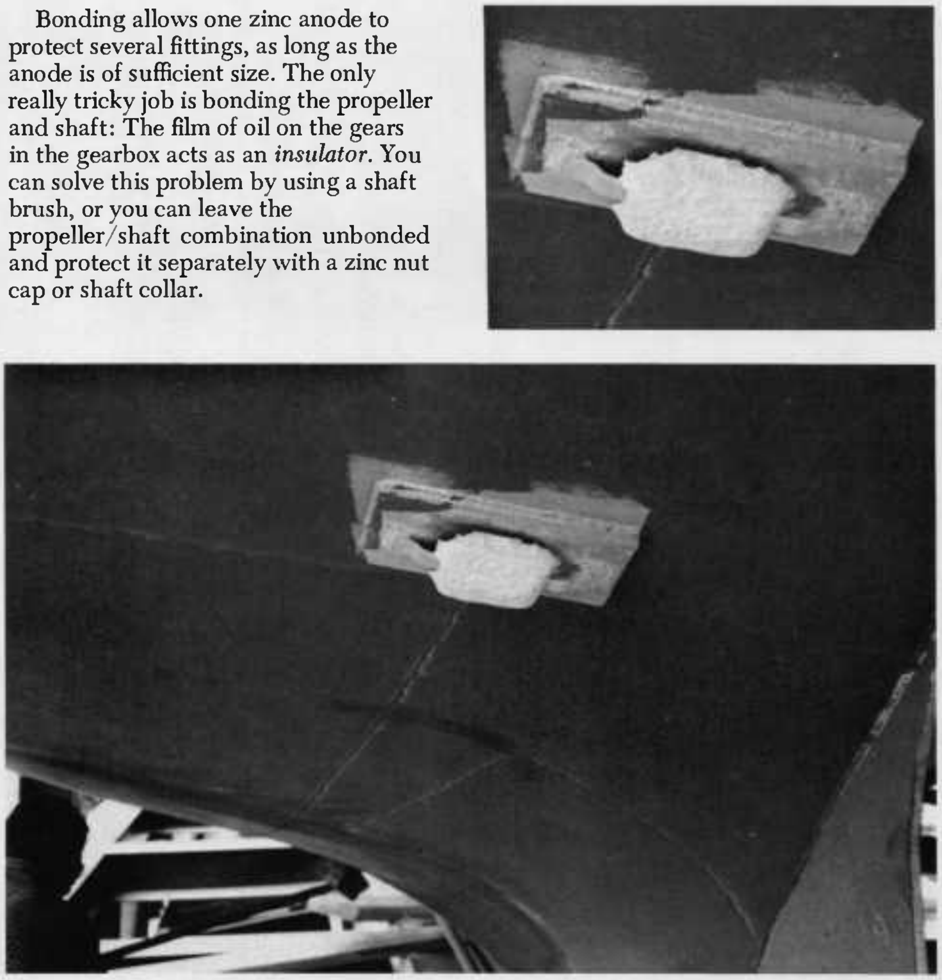
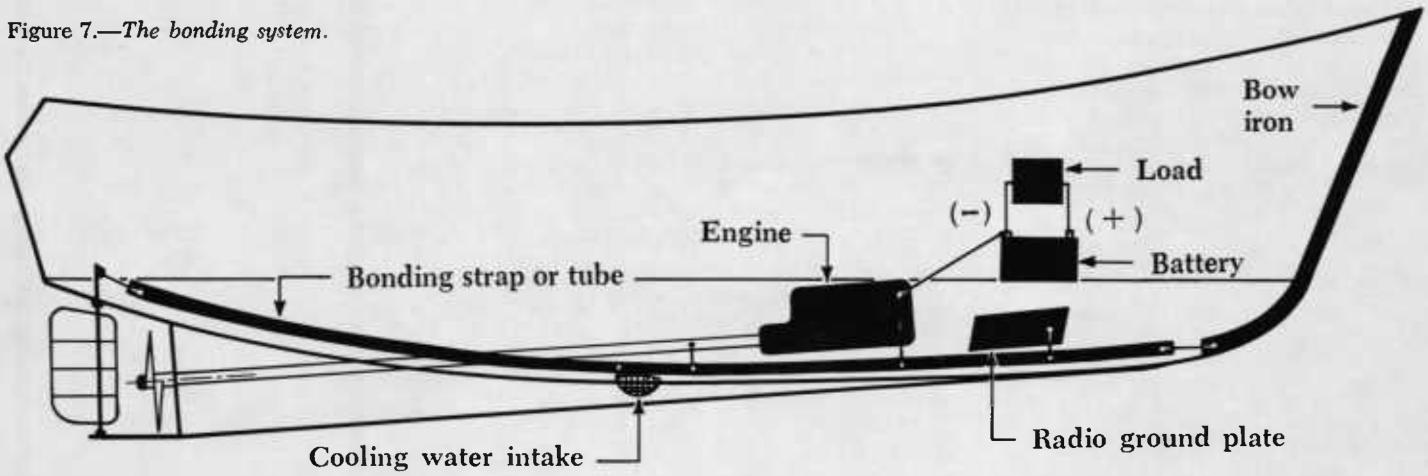


Figure 6.—*A properly corroding zinc anode: (above) a closeup of the anode; (below) a fuller view of the hull area.*

Figure 7.—*The bonding system.*



Stray-current corrosion

Sometimes a boat will experience rapid corrosion of zincs and/or underwater metal fittings, even while sitting at dockside. When this happens, stray current is probably the culprit.

In a d.c. system, stray current is caused by faulty or inadequate boat wiring. To keep on top of this situation:

1. Be sure your boat is wired properly, using adequate wire sizes and well sealed connections. It is also best to use a negative ground system.
2. Be sure that all major metal components, plus all metal through-hull fittings, are bonded and that the bonding system is tied to ground (usually at the engine).
3. Be sure that exposed terminals or other circuit components are not in contact with seawater or seawater-soaked wood.

There is another type of corrosion, a.c. stray-current corrosion, but the results are the same—disaster. When you tie your boat into shore power in some ports, the ground system may connect to other boats' grounds through the neutral side of the a.c. shore power on the dock. Situations can arise that allow a.c. stray currents to flow between your boat and the dock or nearby boats.

To guard against these dangers, your best defense is an isolation transformer. As the name implies, such a device isolates your boat's electrical system from unwanted currents, but it allows a.c. power to go where you want it.

There are other devices that can help to prevent dockside electrical problems: isolators, polarity indicators, reference electrodes, and ground fault circuit interrupters. Check with a marine electrician about applying any of them in your moorage.

Battery chargers—especially older, nonisolating ones—can cause a.c. stray-current corrosion; use only UL-approved chargers. Some mariners disconnect both terminals of the battery as a precaution while charging.

Fortunately, an early warning system exists for all of the problems listed above: a hull-potential meter. Any stray currents will cause erratic or abnormal readings on a hull-potential meter. (Lost or expended zincs also show up as a change in hull potential—another good reason for having a potential-monitoring device aboard.)

Controlled voltage systems

Sacrificial anode systems consist of zinc anodes that have a direct electrical connection to the metal to be protected. There are two cathodic protection systems that operate differently: "controlled zinc" and "impressed current."

In the controlled-zinc system, you connect the zinc anodes to the underwater metals through an electronic controller. This device continually senses the hull potential (using a permanently mounted reference cell), then automatically adjusts the potential it senses to the correct value. It does this by varying the resistance between zinc and protected metal.

Controlled-zinc systems are useful primarily on wood and fiberglass boats. Their advantages over zinc systems that have no electronic controls are: longer anode life, insurance against overprotection, and a built-in meter that continually tells what your hull potential is. Disadvantages are: higher initial cost and need to inspect the system periodically.

Two manufacturers of controlled zinc systems are:

Bartell Marine Electronics, Newport Beach, Calif.
Electro-Guard Corrosion Control Systems, San Diego, Calif.

A second controlled voltage system is commonly called an "impressed-current" device. It, too, uses an electronic controller to sense and adjust hull potential; instead of using zinc anodes to make the voltage change, it draws energy from the boat's batteries or onboard power system. Current flows through special nonsacrificing anodes, instead of through zinc anodes.

Impressed-current devices are most commonly used aboard larger commercial vessels but are available for all sizes of boats. They offer the advantages of continuous protection without overprotection, decreased maintenance at haul-out time, no need to replace expended zincs, and a built-in hull-potential meter. The chief disadvantage is high initial cost; others are that you must pay close attention to your monitor system and maintain a log of performance and operating characteristics. As your boat's battery is in continuous use with an impressed-current device, you must keep it charged. One of these devices can drain a battery in a few weeks!

Here are several manufacturers of impressed-current devices (an asterisk indicates an application limited to small boats having outboards or stern drives):

Calpico, Inc., San Francisco, Calif.
Corrosion Control Associates, Richmond, Calif.
Engelhard Industries Div. ("Capac"), Union City, N. J.
Mercury Marine ("Quicksilver"), Fond du Lac, Wis.*
Norton Corrosion, Ltd., Woodinville, Wash.
Outboard Marine Corp. ("ECP Corrosion Provention Kit"), Galesburg, Ill.*
Wilson Walton International, Inc. ("Aquamatic"), Hoboken, N. J.

Glossary

Cathodic protection—The practice of protecting underwater metal parts by connecting them to sacrificial anodes that are more prone to corrode, or by using an impressed-current device.

Conductor—A substance or body capable of transmitting electrical current—that is, having very low resistance.

Corrosion—The gradual destruction of a metal surface through chemical action.

Current—The flow of charge (electrons or other charged particles) in an electrical circuit. The unit of current is the ampere or "amp."

Electrolysis—Traditionally, this term has described all forms of electrochemical corrosion, including both galvanic action and stray-current corrosion. Strictly speaking, it is the producing of chemical changes by passing an electric current through an electrolyte.

Electrolyte—A solution that contains charged particles ("ions") and, therefore, conducts electricity.

Electrons—Elementary particles having a single negative charge.

Galvanic action—When two different metals are immersed in an electrolyte and connected together electrically, either directly or by a conductor, a current will flow from one to the other. The metal more prone to corrosion will corrode; the other will be protected. This effect is called *galvanic action.*

Hull potential—The voltage of the hull measured with respect to a reference electrode.

Impressed-current system—a cathodic-protection system that uses a boat's battery as a source of current to control the electrical potential of underwater metals.

Insulator—A substance or body with very high resistance, and thus a very low ability to transmit electrical current.

Ion—An electrically charged atom or molecule.

Potential—see *Voltage.*

Reference electrode—Voltages must always be measured between two points. The reference electrode serves as one point for measuring the potential of another object, the other point—for example, underwater metal fittings.

Resistance—Anything that impedes the current flow in a d.c. circuit; the unit of resistance is the ohm.

Stray-current corrosion—If a voltage difference is accidentally impressed on two underwater metal components, one of them (the more positive one) will corrode. This effect is called *stray-current corrosion.*

Voltage (potential)—The driving force for current flow in a circuit; the unit of voltage is the volt.

Zinc sacrificial anode—A piece of zinc that, when directly connected to an underwater metal, protects the metal from corrosion.

For further information

Boat electrical systems and bonding

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