BEST PRACTICES

Bonding Basics

The best corrosion protection for underwater metal fittings is a well-designed and -maintained bonding system.

by Steve D'Antonio

Above—*Cutless bearing shells are typically made from brass, and unless galvanically protected through a bonding system, they will dezincify readily, as this one has. The good news is that brass is less noble than most struts, which means the bearing shell will be sacrificed before the more-expensive and difficult-to-replace strut.*

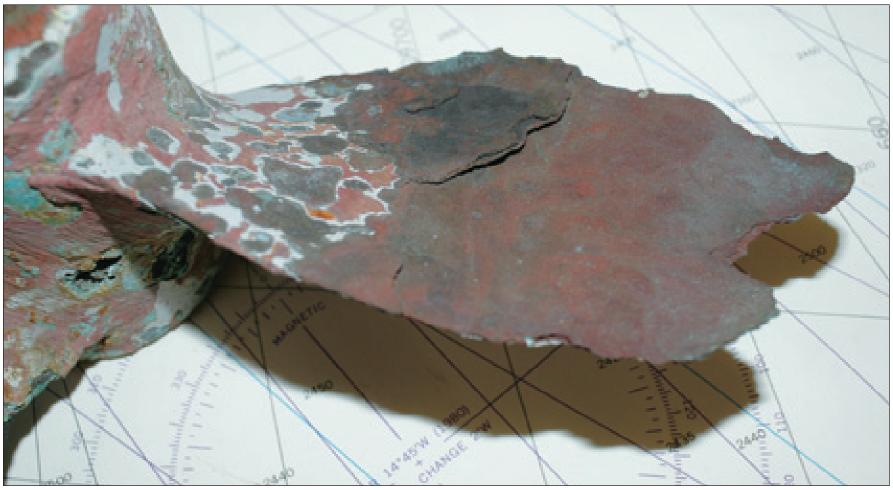
During a recent boat inspection at a local yard, I noticed a marked disparity in the condition of two sacrificial anodes on the vessel's transom. Commonly referred to as zincs, although they can be cast from other alloys, one had been consumed at a rate I thought consistent with the vessel's season afloat—it was reduced by roughly 50%. The other remained in a near-virgin condition. I'd seen this phenomenon before and knew immediately something was amiss with the bonding system.

When it comes to corrosion and bonding, boats can suffer the effects of a faulty electrical system in ways that are not immediately obvious to their owners. It's up to vigilant yard crews to notice the sometimes subtle indicators, track down and remedy bonding problems, and educate owners about this complex and often misunderstood subject.

The Nature of the Beast

Many seemingly inexplicable corrosion problems are often chalked up, sometimes even by professionals, to "a bad ground." While the crews or technicians making this dismissive assessment are often accurate, they are also frequently at a loss to explain just why this is so. Indeed, while many understand that it's important and valuable to have a bonding system, far fewer truly understand what it is or how it works. Let's start with some basics of grounding and bonding systems.

From a standards perspective the subject is complex, encompassing guidelines from at least two American Boat & Yacht Council (ABYC) standards: *E-2 Cathodic Protection* and *E-11 AC and DC Electrical Systems,* which focus on corrosion mitigation and electrocution/fire prevention, respectively. Although there are



The effects of stray-current corrosion on this propeller were dramatic, rapid, and unmistakable. They could have been avoided with adequate bonding.

significant differences between grounding and bonding systems, the terms *bonding* and *grounding* are frequently applied interchangeably. Here, I'll focus on the goal of corrosion mitigation and stick to the term *bonding*. In brief, a bonding system electrically connects underwater metal fittings such as through-hull fittings/seacocks, rudders, and struts.

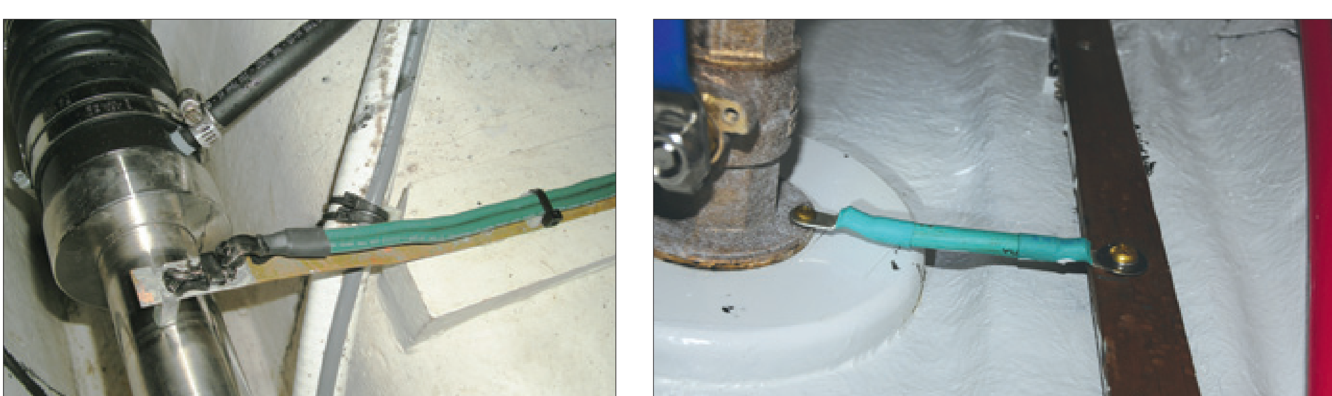
Propeller shafts may be included in the system; however, because they are connected to the engine via an oil-filled medium—the transmission—and because oil is an insulator, the connection cannot be considered electrically sound. In order for propeller shafts and propellers to be included in the bonding system, they must rely on a shaft brush, a device that completes a low-resistance connection to the bonding system.

Shaft brushes are specifically designed to maintain contact with a rotating surface. They resemble the brush in an electric motor's commutator and should be made from the same material: carbon. (Some use a hunk of bronze or brass, both of which are less effective.) To complete connections between these components for the purpose of bonding, the conductors should be a minimum of #8 AWG. If doing double duty as a lightning-protection system, they must be a minimum of #6 AWG.

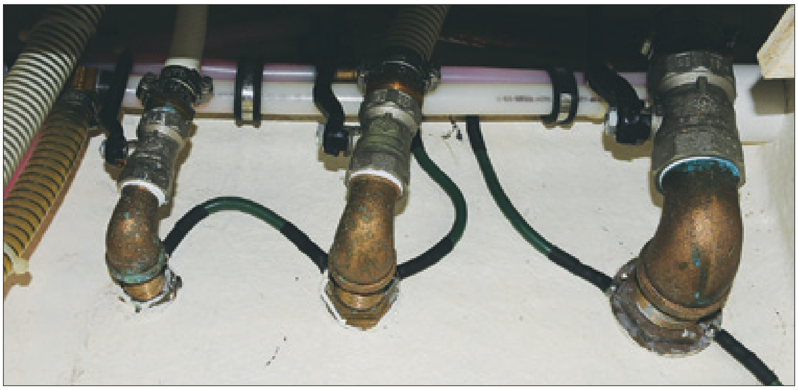
Rather than interconnecting each item to the next in a daisy chain, bonding systems are more reliable and present lower overall resistance when they rely on central bonding buses. These are copper strips that run the length of the vessel, with various items connected by short lengths of wire. A strip should be a minimum of 1⁄32″ (0.8mm) thick and no less than ½″ (12mm) wide. The connections to it are critically important. In no case should they be secured with self-tapping, sheet-metal, or wood screws. If machine screws are applied, the strip must be thick enough to be tapped and must allow a minimum of four threads of engagement. In other cases, through-bolts and nuts may be used to connect a wire's ring terminal to the strip.

Too often I see wiring ring terminals connected to a bonding strip with self-tapping screws that pass through the strip and into fiberglass or wood, assuring a poor connection. Such connections are not ABYC compliant, and when I inspect vessels whose bonding systems are wired in this manner, I find loose connections almost every time.

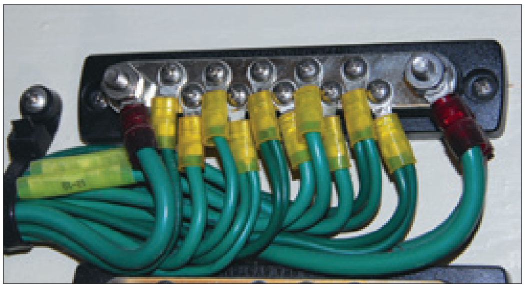
If there's no bonding strip, and components are connected one to the other via wires, avoid making connections through hardware. That is to say, if two bonding wires are



Left—*Not all shaft brushes are created equal. Much like the brush contacting an electric motor's commutator, the business end that rides on the shaft should be made of carbon rather than simply a hunk of bronze pipe or rubrail.* ***Right—****A central bonding strip or bus running the length of a boat allows for bonding wires to be attached anywhere, which keeps those wire runs shorter and reduces resistance. If the strip runs along the inside of the hull well above the bilge, corrosion at connections is minimal.*



Above—*Daisy-chaining bonding wires from fitting to fitting is common and often unavoidable. However, protected components should* not *serve as a path for current as they do here with ring terminals connecting on either side of the fitting. Instead, the terminals should be stacked one on top of the other* ***(above right)****. Fully 75% of the bonding ring terminals I check are loose. They should be retained with machine screws, never self-tapping screws, regardless of the substrate.* ***Right—****In the absence of a central bonding strip, bonding bus bars can be placed throughout a vessel to keep drops to individual components short and reduce to the number of connections at each bonded component.*



connected to a single component, such as a seacock or strainer, install both ring terminals on the same fastener and stud—rather than separately. This prevents the bonding system's low voltage and current from relying on the comparatively high resistance of the hardware component as a conductive medium.

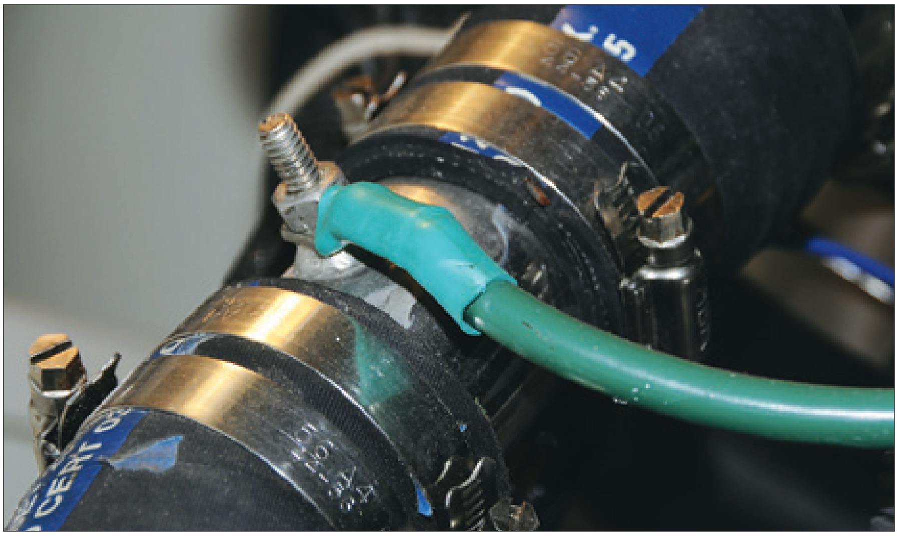
An alternative to the stem-to-stern copper bus bar is required for most after-build installations. In this situation, the best way to make reliable bonding points is to install an interconnected series of off-the-shelf tin-plated bonding bus bars in various locations around the vessel's machinery and bilge space.

Because the voltage and current that such a system is called on to transport are often quite low, the resistance must be equally low. In a bonding system, the soundness of all connections bears heavily on its effectiveness. Resistance between any two points in the system must not exceed 1 ohm. This is a high standard for conductivity, indeed, and a tall order since so many bonding connections are located in the bilge. To ensure long-term reliability, you should coat connections with a corrosion inhibitor that's also conductive. And, periodically inspect all bonding system connections for corrosion and fastener tension.

The reasons for interconnecting all of this seemingly disparate gear are twofold. First, bonding provides a low-current path to ground for stray current. Typically caused by a positive DC wire, often from a bilge pump, which comes into contact with bilge water, stray-current corrosion is especially destructive. In a matter of days, it can consume a propeller or turn a shaft into a useless mass riddled with holes. A sound bonding system reduces—although does not eliminate—the likelihood of severe stray-current-corrosion damage.

Second, when the bonding system is connected to a sacrificial anode, that anode will then afford protection to *all* metals that are interconnected *and immersed in the same body of water*. (Typically, "the same body of water" is limited to the water in which these components are immersed, but the definition does not include those connected through water in hoses.) This arrangement makes it considerably easier to protect multiple metals by maintaining just a few anodes.

Hull anodes will do nothing to prevent corrosion within the engine and generator, even if they are connected



Anodic protection is effective only when the anode and the hardware being protected are immersed in the same body of water. Fittings such as this cooling system connection, regardless of being dutifully bonded, are afforded little protection against corrosion by the hull or engine anodes.

to the bonding system. Although the engine and generator contain seawater, for all intents and purposes that is not the same water the vessel floats in. A common flaw I encounter is that, in spite of often being bonded, metallic raw-water plumbing components installed deep within many vessels are afforded little if any protection. In these cases, where such protection is deemed necessary, non-metallic options such as FRP and proprietary plastics designated for raw-water use offer a preferable alternative.

Slower and more insidious than stray-current corrosion, galvanic corrosion can take months or years to do its dirty work. Also DC-related, this type of corrosion is typically the result of setting up a cell between dissimilar metals that are far apart on the galvanic series—aluminum and copper, for instance—and immersing it in an electrolyte such as seawater (see *Professional BoatBuilder* Nos. 32 and 33). In defending against stray-current and galvanic corrosion, a sound bonding system and good anodic protection are key elements. The bonding system in particular may reduce or delay corrosion by affording stray current a return path to ground that excludes immersed metals.

Instances of uneven anode depletion often indicate problems in a vessel's bonding system or anode installation. They also can be a function of variation in alloy quality and specific anode design. On the vessel I inspected in the boatyard, the problem turned out to be poor contact between the anode and the mounting stud, a common scenario that should not be ignored.

Advice to Technicians

For anodes mounted to the hull, carefully inspect the studs and the wiring attached to them inside the hull. The wiring is often immersed in bilgewater, making it extra vulnerable to corrosion. Clean the external portion, and make sure it is free of any scale or marine growth. The stud should remain captive to the hull regardless of whether an anode is installed or not, and there should be a gap between the back of the anode and the hull.

If necessary, remove the anodes and clean the hardware with emery cloth or a stainless steel or bronze wire brush. Avoid cleaning anodes with an ordinary mild-steel wire brush, as it will leave behind steel deposits that will rust. Make certain that fasteners such as washers and lock washers holding anodes in place are secure, and install them in the correct order. The lock washer should always rest directly under the nut, and hull anodes attached to studs should rely on an embedded contact plate to assure continued contact with the mounting stud as the anode's active material corrodes away. If the anode has no such plate, or if it's covered with anode material, contact with the stud is often quickly lost, and in some cases the anode may loosen or even fall off.

Before installing a new anode over other hardware, such as rudders, propeller shafts, or trim tabs, be sure to clean the attachment surface with

Beware the Bilge

Onboard wiring should always be routed above normal bilgewater levels. In areas such as around bilge pumps and switches where you cannot avoid this, pay careful attention to your wire routing and connection methods. My own rule for bilge-pump and related component wiring calls for all connections to be made 18″ (46cm) above the top of the pump, using a tin-plated, insulated terminal strip that, upon completion of the assembly, I spray with a corrosion inhibitor. As an alternative, or where the 18″ elevation is not possible, I rely on waterproof heat-shrink butt splices. Still, in my experience, the source of stray-current corrosion is often damaged float-switch-wiring insulation, so I recommend that you route it out of harm's way, and inspect it regularly for any signs of failure or corrosion.

—*Steve D'Antonio*

Electrical connections made within reach of bilgewater are a stray-current-corrosion catastrophe in the making. Connections for bilge pumps and switches—the only ones that should be close to bilgewater—must either be a minimum of 18" (46cm) above the base of the pump, or be fully waterproof. Neither installation above is ideal.

Left—*When boat owners boast that their anodes last a very long time, suggest an analysis of the anodes, their attachment to the bonding system, or of the entire bonding system.* ***Right***—*This corroded hull anode reveals the cast-in plate through which the mechanical and electrical connections are made to the hull. This construction ensures that consumption has no effect on the connection or security of the anode.*

emery cloth or bronze wool. If you install an anode over a surface that is contaminated with scale, paint, or other debris, you will be compromising the protection.

Anodes that last an unusually long time are suspect. With the vessel hauled, use an ohm meter to check the soundness of the bonding system by connecting one lead to the anode and the other to bonded underwater metal hardware such as a through-hull fitting, strut, or rudder. Note that you may need to make extra-long leads to perform this test. Remember,

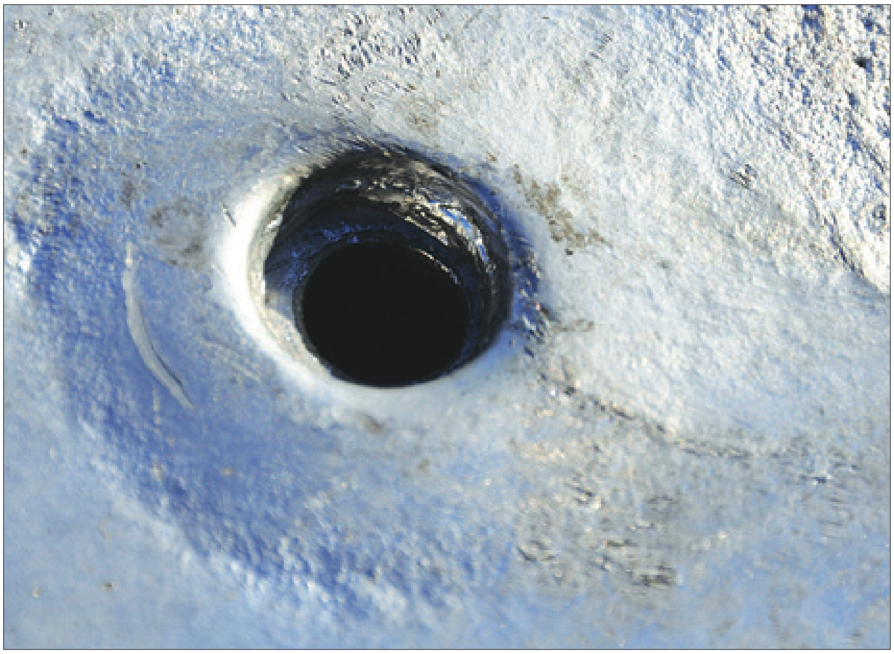
Studs on a new boat await installation of a hull anode. When completed, there should be a gap between the back of the anode and the hull.

resistance between any two bonded underwater metals and between any metals and an anode should, ideally, not exceed 1 ohm. If the resistance is higher than that, then either the hull anode is not making good contact with its mounting studs, or the bonding-system wiring is compromised by corrosion, a loose connection, or both.

Anode Alloys

Anodes come in different alloys: aluminum, magnesium, and zinc. Traditionally, fiberglass vessels operating in seawater have used zinc, because it provides more than adequate protection for common underwater metals such as stainless steel and bronze. However, zinc anodes are less effective in fresh or brackish water. The relative energy capacity of zinc is 368 amp-hours per pound, and its voltage is –1,050 millivolts. Remember those numbers. In corrosion-speak, the more negative the voltage, the better.

Aluminum anodes are well suited for use in seawater as well as in brackish and fresh water. Aluminum anodes make the most sense for customers who sail in those different waters. Where I live on the lower Chesapeake Bay, the salinity of the countless creeks, inlets, and harbors can be affected by rainfall. One week they may be saline, the next they may



As the metal is consumed, anodes are prone to contact failure when they rely on the anodic material itself—most commonly zinc or aluminum—to complete an electrical connection with the mounting hardware.

be brackish or even fresh. This makes it desirable to install an anode that will work in fresh and salt water.

Aluminum anodes also pack more of an electrical punch, and they last longer than zinc anodes of the same weight. The relative energy capacity of an aluminum anode is 1,108 amp-hours per pound, with a voltage of 1,050 millivolts. If you opt for aluminum anodes, the change should be made for all anodes used in the same bonding system.

Surprisingly, aluminum anodes are often no more costly than zincs, yet zincs remain the norm on most boats. My theory is that people either don't know about aluminum anodes and their advantages, or they are simply reluctant to change anything associated with corrosion protection and prevention. (For more on aluminum anodes, see PBB No. 136, page 15.)

Magnesium is an alloy reserved primarily for fresh water. If that's the *only* place a vessel is operated, then consider it as *the* anode material.

Whichever anode you select, be certain it carries a military specification approval. That ensures, among other things, that what you install it is free of an excessive amount of other

Galvanic isolators are one line of defense in the fight against dockside shore-power-connection-induced corrosion. They reduce the possibility of accelerated anode consumption when boat owners plug cords into shore power.

trace metals that offer no corrosion protection.

The rate at which any anode is consumed is a function of its size—and how much metal it is protecting. In simple terms, if anodes remain unchanged with use, something's probably wrong with the bonding system, and underwater metals may not be properly protected. If they are consumed too rapidly, or if the rate increases noticeably, there's probably something wrong with the system, or stray current corrosion is at work. Owners need to be educated about these symptoms, and they need to understand that once the anodes are gone, the next least noble metal—often the propeller or sterndrive—will corrode the same way the anodes did.

Shore-Power Cable Problems

Even if the bonding system and anodes are in top working condition, a boat may still suffer from rapid anode consumption or corrosion of underwater metals. The likely culprit in this scenario is often the shore-power cable. Note, I said shore-power *cable* and not shore power. It's a common misconception that shore power causes corrosion. The subject of AC power-induced corrosion has been discussed in these pages (see PBB Nos. 100 and 108). But in the vast majority of cases, corrosion that occurs as a result of plugging into shore power is, in fact, DC in nature. Read on.

The shore-power cable's important green grounding wire ensures that a shore-power fault aboard the vessel will be safely carried to ground. Without the ground wire, or if it's installed incorrectly or is in poor repair, the result could be a fire or electrocution. This grounding wire is, by necessity, connected to the vessel's bonding system and, through it, to the anodes. Thus, whenever the vessel is plugged into shore power, the bonding system and anodes are connected to some or all of the dock's other vessels, as well as to their underwater metals and anodes. As a result, the vessel's anodes could actually be protecting the underwater metals of adjacent vessels, especially if those vessels' own anodes are depleted.

This is a simple case of galvanic corrosion, and it has nothing to do with the AC shore power itself. The connection is made via the shore-power cable and its green safety ground wire. Even if the shore power is turned off, the green ground wire remains connected whenever the shore-power cable is plugged in to the boat and the dock pedestal; as long the cable is connected, destructive galvanic current can flow.

There are two possible solutions to this problem. The first is to unplug the shore-power cable whenever it's not being used. In most cases, however, that's not practical: owners and crews want to leave vessels plugged in to keep refrigeration, HVAC systems, and battery chargers operational. The second alternative is to install a relatively inexpensive galvanic isolator. This allows AC voltage, including the all-too-important shore-power faults, to pass, while blocking DC voltage. When the vessel is plugged into shore power, it is isolated from other vessels' AC grounds and bonding systems and is no longer protecting a neighboring boat that hasn't had its anodes changed in two years.

Another, more expensive solution that offers additional advantages is an isolation transformer. (For more detail on isolation transformers, see PBB Nos. 103 and 108.)

Diagnosing the Fault

In the case of the vessel whose anodes were consumed at an uneven rate, a few hours of testing revealed some interesting details. The boat was equipped with two galvanic isolators, one for each of the 30-amp shore-power services. I determined that they had been installed in accordance with ABYC standard *A-28 Galvanic Isolators*, which meant that any issues were likely the vessel's own, rather than those of a neighboring boat. Then, applying the diode test function of a digital multimeter, I confirmed that the isolators were blocking DC voltage and were otherwise operating correctly. Again using the multimeter, I concluded that resistance between the nondepleting anode and its mounting studs was

You don't need a multimeter to identify faults with anodic protection or bonding systems; uneven anode consumption is often a sign of trouble that should be investigated.

poor. When the anode was ultimately replaced, the ohm meter confirmed a sound connection.

Galvanic isolators are well worth the comparatively small expense. Even if your customer plugs into shore power for just a day or two a year, it makes sense to recommend a galvanic isolator. As one might expect, not all galvanic isolators are created equal. Select the ones you recommend and install based on the following criteria:

- A fail-safe design that, even in the event of a catastrophic internal fault or a lightning strike, ensures that the isolator will still safely and reliably conduct AC fault current to ground even though it may no longer isolate galvanic current.
- Full compliance with ABYC standard *A-28 Galvanic Isolators* most recently revised as of July 2008.
- UL Marine approval.

Bonding systems and their associated anodes play a vital role in protecting a vessel against corrosion; however, they will only function as designed if properly installed and maintained. Since the average vessel owner lacks the knowledge and skills to carry out such inspections and service, the builder or boatyard must take on the responsibility of providing the necessary services and guidance to maintain this important system. PBB

About the Author: *For many years a full-service yard manager, Steve now works with boat builders and owners and others in the industry as "Steve D'Antonio Marine Consulting." He is the technical editor of* Professional BoatBuilder*, and awaits the publication (by McGraw-Hill/International Marine) of his book on marine systems.*