Taming The Wayward Electron Part II

Controlling Galvanic Corrosion

By Dave Gerr, CEng FRINA © Dave Gerr, 1991 and 2011

In the previous article, we explored the corrosion process, and a method to test a boat and its fittings to determine if they're properly protected. In this issue, we'll take a detailed look at estimating the amount of protection a boat needs, and how it should be installed.

How Much Protection?
In part one, we saw that the way to protect metals from galvanic corrosion is to flood them with excess electrons. These electrons come from zinc anodes. How much zinc is required? How much is too much? A good way to determine this is by testing on board. When your *Dry Roller*'s going to be snugged up at its mooring for a few days, take several zinc anodes—about as many as you think should do the job—and connect them temporarily with wires to its hull or the fittings to be protected. (If it’s a wood or FRP/fiberglass craft, connect to the bonding system. If your *Dry Roller* is metal, connect to the hull itself.)

Dangle the zincs in the water. Twelve to 24 hours later, *Dry Roller*'s hull and/or its fittings will have fully polarized from these anodes. Referring to the galvanic series and the testing method described last issue, you can go around checking results with a multimeter. If you need more or less zinc it will be obvious from the voltage readings. (Cover one side of the anodes with tape or plastic during the test. This side will, of course, be against the hull after the anodes are installed. If you forget to do this, the anodes will have excess surface during testing.)

Severely Corroded Bronze Propeller
Photos: Paul Bremer

Estimating The Anodes Required
Most builders, yards and boat owners don’t approach the anode quantity problem so systematically. Many simply slap a few anodes on haphazardly—a shaft collar, a zinc on the strut, perhaps a pair of teardrops on the rudder—and hope for the best. In fact, even without running an actual test to determine zinc quantity, reasonable estimates of anode quantity can be made.

Now, there's a basic subdivision between boats—metal-hulls (steel and aluminum) and non-metal (wood and fiberglass). On metal hulls, the anode’s (zinc's) job is to protect the hull from galvanic attack by the other metal fittings—almost invariably of more noble metals—and from attack from itself. (Small variations in the amount carbon, oxygen or hydrogen—the effects on the metal of welding, and cold working—change the composition of local regions in the hull. This creates differing potentials that can cause galvanic corrosion within the plating itself.) By contrast, on wood and FRP vessels, the anode's job is to protect differing metals among the fittings from attacking each other.

Anodes for Wood and FRP Craft
The principle underwater fittings on wood and FRP craft are the, propeller and shaft assemblies, and the rudder. (Parts of the exhaust, through-hulls, tanks, and so on may also need protection.) The zincs that come installed on most boats, aren't the best system. They do, however, provide basic protection. Customarily, zinc collars are fitted around the shaft and occasionally—for additional protection—a zinc prop nut is fitted to the end of the shaft. Zincs are also fastened to the struts themselves as well as to the rudder.

Using this approach, if *Dry Roller* were single-screw, with its shaft emerging from a bearing in a centerline keel, a short square-sectioned ring collar would fitted around the shaft between the prop and the bearing. If it had long exposed shafts—most commonly on twin-screw boats—a single streamlined zinc collar would be installed around each shaft. Zincs also come in teardrop and streamlined shapes for installation on the sides of rudders and struts, and in slabs and blocks (some quite large) for use on metal hulls.

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The Single-Anode System

Although zinc shaft collars and prop nuts are most common, a much superior system is to install a single zinc anode (or a few electrically connected together) mounted on the hull to protect each shaft/prop assembly. (The rudder should be included if it is stainless steel or bronze.) Install the anode anywhere it can "see" the prop and shaft. The anode is through bolted onto the outside of the hull. Run a bonding conductor from a zinc-fastening bolt, on the inside of the hull, to the engine block. You also connect to the shaft log, the rudder stock (if metal) and the prop shaft.

Bonding System

In fact, all the metal components in the hull (deck gear need not be included) should be connected to the zincs—tanks, machinery, hardware, and fittings. The standard system is to run a heavy or main bonding conductor down the length of the hull and connect all the hardware and fittings to that with shorter bonding jumpers. The zinc (or zincs) are connected to the main bonding conductor with jumper wires, thus protecting all the bonded hardware. Bonding conductors should be sized from Table 1.

Resistance in the bonding system should not exceed 0.01 ohms (Ω). Copper straps or tubing of the specified cross-sectional area are excellent. On wood and FRP craft, the bonding conductors need not be insulated.

Table 1 - Bonding Conductor Sizes

Length of Run	AWG - American Wire Gauge	Diameter	Cross-Sectional Area
less than 20 ft.	8 or larger	just over 1/8-inch dia.	0.013 sq.in
20 ft. to 40 ft.	4 or larger	just under 7/32-inch dia.	0.033 sq.in.
40 ft. and over	2 or larger	just over 1/4-inch dia.	0.052 sq.in.

Making Your Zincs Work

It takes some smarts to make zincs work.

1) You must install zincs to protect your boat's metal fittings or hull.
2) The zincs must be in tight clean electric contact with the metal components they're protecting. (If they're not electrically connected to the bonding system or metal hull, they're useless.)
3) The surface of the zincs must be exposed to the water. You can't paint a zinc anode ever! You want it exposed, and you want it to corrode. (They're not called "sacrificial zincs" for nothing!)

If your *Daffy Dancer*'s zincs aren't wearing away, they're either way, way too large (unlikely); not in proper contact with the metals they're protecting; or they're painted over. In any of these cases, *Daffy Dancer*'s zincs would be useless.

Properly sized, the zincs on *Daffy Dancer,* or any boat, should last about a year, at which time they'll be about half gone. You have to remember to check the zincs whenever possible to see that they're firmly attached and corroding properly. You also have to remember to install new zincs at the beginning of every season. Forget, and you'll likely end up replacing the prop or shaft instead—not sound economy!

Locating Your Zincs

Zinc anodes should be located correctly for maximum effectiveness. The following will serve as a general guide:

<u>2 Zinc System</u>:
1 each port & starboard about 33% or the WL (waterline) forward of the transom

<u>4 Zinc System</u>:
2 each port & starboard, 2 about 20% of WL forward of the transom & 2 about 53% forward of the transom

<u>6 Zinc System</u>:
3 each port & starboard, 2 about 16% of WL forward of the transom, 2 about 42% forward of the transom, 2 about 66% forward of the transom

<u>8 Zinc System</u>:
4 each port and starboard, 2 about 14% of WL forward of transom (about 70% of beam out toward the bilge), 2 about 16% forward of transom (on or near the keel), 2 about 42% forward of the transom, and 2 about 66% forward of the transom.

To hook up the rudder stock, you simply have to use a slack bonding strap/wire so the rudder can turn freely through 90°. (A stainless hose clamp makes a good fastener.) To connect to the prop shaft, however, you must use a shaft brush. These cost around $50 apiece and last for years. They are simple bronze or brass plates or strips with a graphite "brush" on one end and several mounting bolt holes on the other. The shaft brush is fastened to a bracket so the brush presses on the shaft. (The whole rig is very much like the commutator brushes inside an electric motor.) The bonding wire is fastened to a lug on the brush and run to the main bonding conductor. Make certain that all the electric connections are clean and tight. It's amazing how much resistance a little bit of corrosion or a loose wire can produce—quite enough to make your zinc ineffective.

Single-Zinc Advantages

The beauty of the single-zinc system is that you have only one zinc (or group of zincs) to keep track off (two, or two sets, on a twin screw boat). Even better, because everything's bonded to the same anode, all the fittings will float at the same potential; they'll be uniformly protected. With individual zincs attached to different underwater fittings, some items

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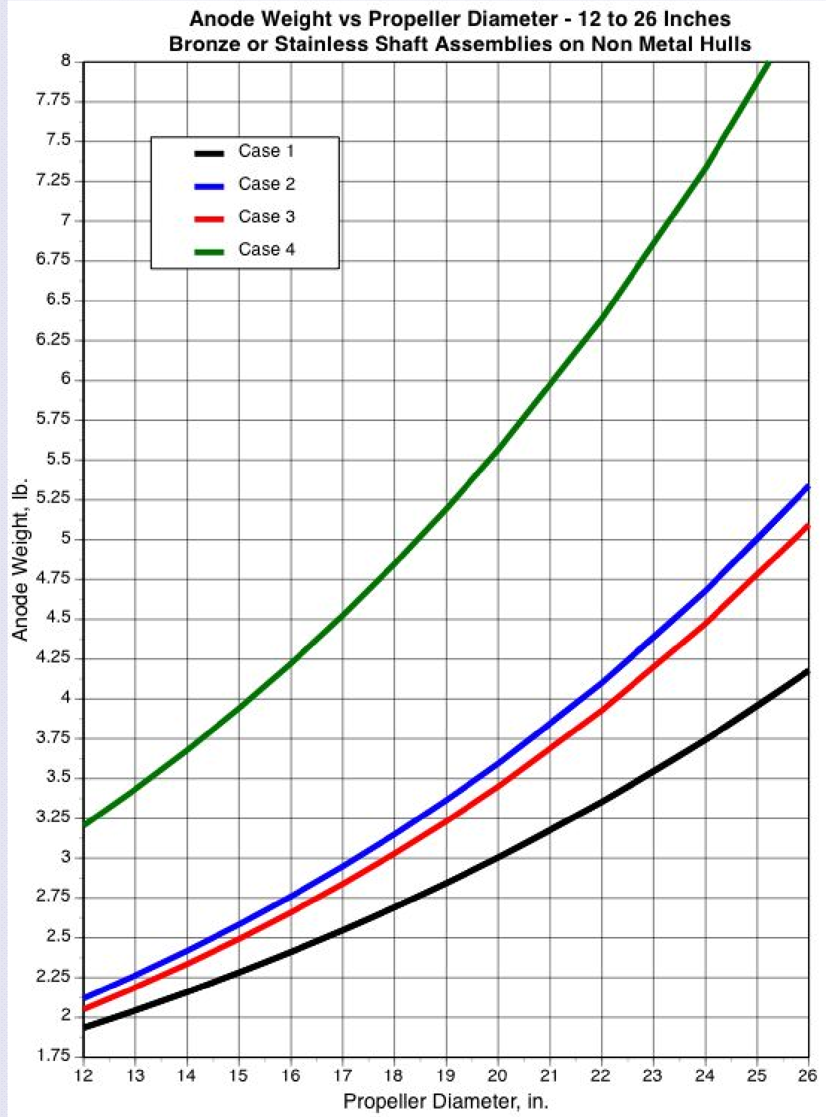
may be over protected, others under protected, still others may not be protected at all.



Controller/Monitors

An even greater advantage is that a zinc controller/monitor can be installed in the bonding system between the zinc (or zincs) and the protected fittings. (The bonding wire is run from the zinc to the controller/monitor and then to the main bonding conductor.) Controller/monitors allow you to adjust the resistance in the bonding system, so you can speed up or slow down how fast *Dry Roller*'s zincs corrode, and how much they polarize the other fittings. Keeping tabs on *Dry Roller*'s bonding system voltage, enables you to be sure that its zincs are working properly; to know when they need replacement; to use the controller to adjust for the zinc's decreased effectiveness with age; to eliminate overprotection; and to spot stray-current corrosion, should it start. This is a lot of pluses, especially on large craft, where corrosion damage can quickly add up to expensive headaches.

One controller/monitor is the Siemens CM2 Corrosion Monitor, www.siemens.com/water. Another source is Caltheco www.cathelco.com/yacht_iccp.htm.

Sizing up the Zinc — Wood and FRP Vessels

For wood and FRP hulls, there're four standard variations of shaft assemblies.

Case I:

Centerline propeller on a single-screw vessel, no exposed shaft and an all-wood or all-fiberglass rudder assembly.

Case 2:

Same as Case 1, but with a bronze or stainless rudder, rudder post, and fittings.

Case 3:

Long exposed shaft and strut assembly, and a wood or fiberglass rudder assembly. (Double the amount for twin screw.)

Case 4:

Long exposed shaft and strut assembly, with bronze or stainless rudder, rudder post, and fittings. (Double the amount for twin screw.)

Wood and FRP vessels are occasionally fitted with mild-steel rudders and fittings. These should *not* be attached to the bonding system, but kept isolated, and protected with separate anodes of their own. A better solution would be to discard the mild steel gear and replace it with stainless or bronze.

By referring to the charts, you can select the correct weight of anode for your boat. Say your *Daffy Dancer* was a 60-foot fiberglass cruiser. *Dancer* is driven by a single 40-inch prop projecting out of the deadwood (no exposed shaft). Its rudder is foam-core fiberglass with a bronze rudder post and fittings. These characteristics make *Daffy Dancer* a Case-2 vessel. Simply enter *Dancer*'s prop diameter on the horizontal axis of the "Anode Weight vs Propeller Diameter" chart and run up to intersect the Case-2 line. Run across and read off the weight of zinc anode required—about 13.4 pounds.

This isn't an exact science only an estimate, so you'd refer to the manufacturer's catalog and order the nearest size up from the size indicated. (In large vessels you may have to use multiple anodes.) If *Daffy Dancer* were a wood craft; remember that overprotection can damage a wood hull especially. You should check the voltages generated by the zincs as soon as you get the chance. (If you have a controller monitor system installed, you have a built in continuous check.)

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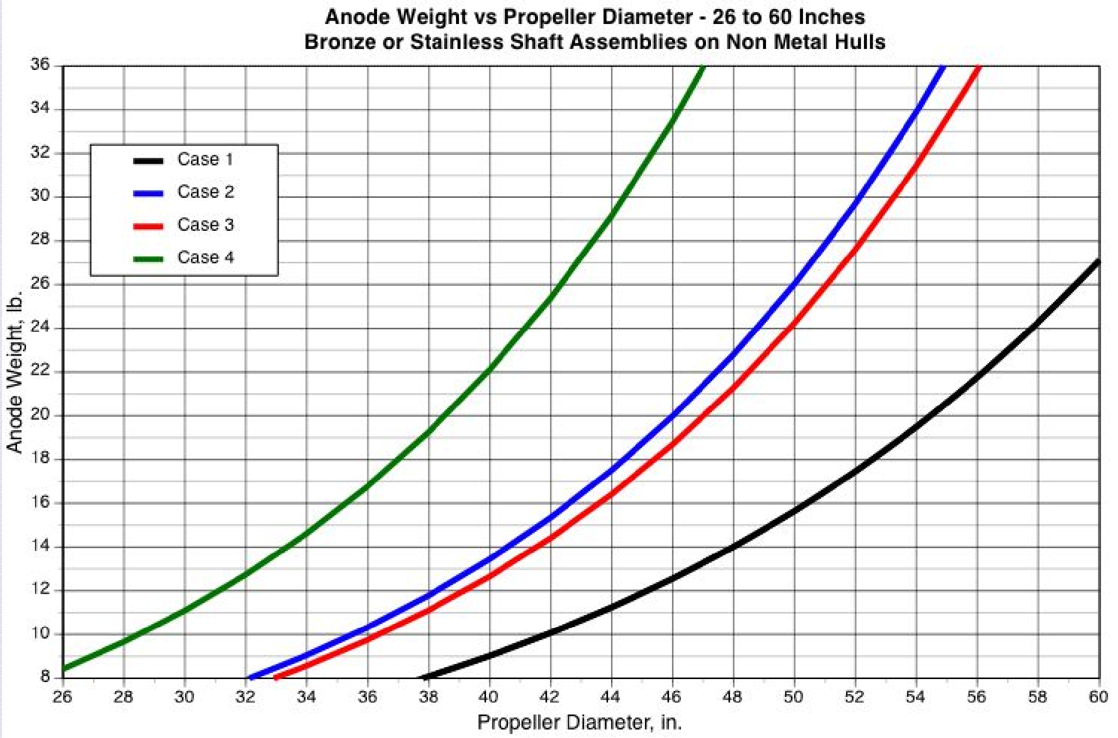

To ensure good electrical contact and a firm mounting base, proper anodes—for steel vessels as well as wood and FRP craft—are cast around a steel-bar core. Fastening bolts penetrate and land on this core. For aluminum hulls, the best practice is to use anodes with aluminum cores.

Amount of Zinc for Metal Hulls

A good estimate of the anode required can be made from the following formulas:

For steel hulls:
For one year protection of a hull with an average (less than perfect) paint job:
Steel-hull required anode weight (lbs.) = Hull Wetted Surface (sq.ft.) ÷ 16.75

For two years of protection use twice as much anode. For one-year protection of bare metal, use 2.5 times as much.

For aluminum hulls, anodes are better selected by their surface area than by their weight:

For aluminum hulls:
For one year protection:
Aluminum-hull required anode surface area (sq.ft.) = Hull Wetted Surface (sq.ft.) ÷ 220

Remember these formulas give estimates. Boats that operate in warm or highly polluted water may need more protection. Vessels that operate in cold clean waters can often get by with less. The best practice is to test polarization, as described earlier.

Steel & Aluminum Hulls

Where wood and FRP vessels require a common bonding system to connect all metal hardware to the anodes, metal hulls themselves form the bonding. On steel hulls, it's possible to weld lugs, projecting from some anodes, directly to the hull. This, however, makes replacing anodes a difficult business. A superior approach is to weld bolts to the hull to mate with the anode's fastener holes. Replacing anodes is then as simple as turning a wrench.

On aluminum craft, the best practice is to weld either a backing or doubler plate to the exterior of the hull, or to weld a thick insert plate into the hull at the anode location. (The doubler or insert plate should be of the same aluminum alloy as the surrounding plate.) Doubler thickness should be at least 1.5 times the fastening bolt diameter; the insert plate at least 2.2 times bolt diameter. Both should match the footprint of the anode, or be slightly larger.) Drill and tap the doubler for the anode mounting bolts (stainless threaded inserts are even better) and use standard 316-stainless hex-head machine bolts to fasten the anode. Be certain to install lock washers under each nut. Without these, engine vibration and corrosion will loosen the nuts. (Note: High-speed aluminum hulls and sailboats that need to reduce drag can use recessed anodes to decrease drag, as shown in the illustration, next page.)

Anode Weight Formulas

If you prefer use the formulas for anode weight in a spreadsheet, they are:

Case I:
Anode wgt., lb. = $e^{(0.055 \text{ x Dia., in.})}$

Case 2:
Anode wgt., lb. = 0.96 x $e^{(0.066 \text{ x Dia., in.})}$

Case 3:
Anode wgt., lb. = 0.94 x $e^{(0.066 \text{ x Dia., in.})}$

Case 4:
Anode wgt., lb. = 1.4 x $e^{(0.069 \text{ x Dia., in.})}$

Where: $e \approx 2.7183$

Metal Hulls Must be Isolated

Keep in mind that metals more than 200 mV (millivolts or 0.2 volts) apart should not be in contact in salt water. This means that all yellow-metal and stainless fittings must be isolated from the metal hull using non-conducting insulation and bedding compound. On smaller vessels, such fittings can simply be left totally isolated. They will be floating at

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freely corroding potential in this condition, but—if they're proper marine alloys—will last many, many years.

On larger craft, the isolated fittings should be connected to their own *completely separate and completely isolated* secondary internal bonding system—just as on a wood or FRP craft. (Bonding conductors on these secondary systems *must* be insulated to avoid contact with the hull.) Even the zinc anode(s) for this separate system must be completely isolated from the metal hull. Dual-metal corrosion controllers are available to monitor the hull anodes, as well as to monitor and control the isolated secondary bonding system.

Estimating Hull Surface

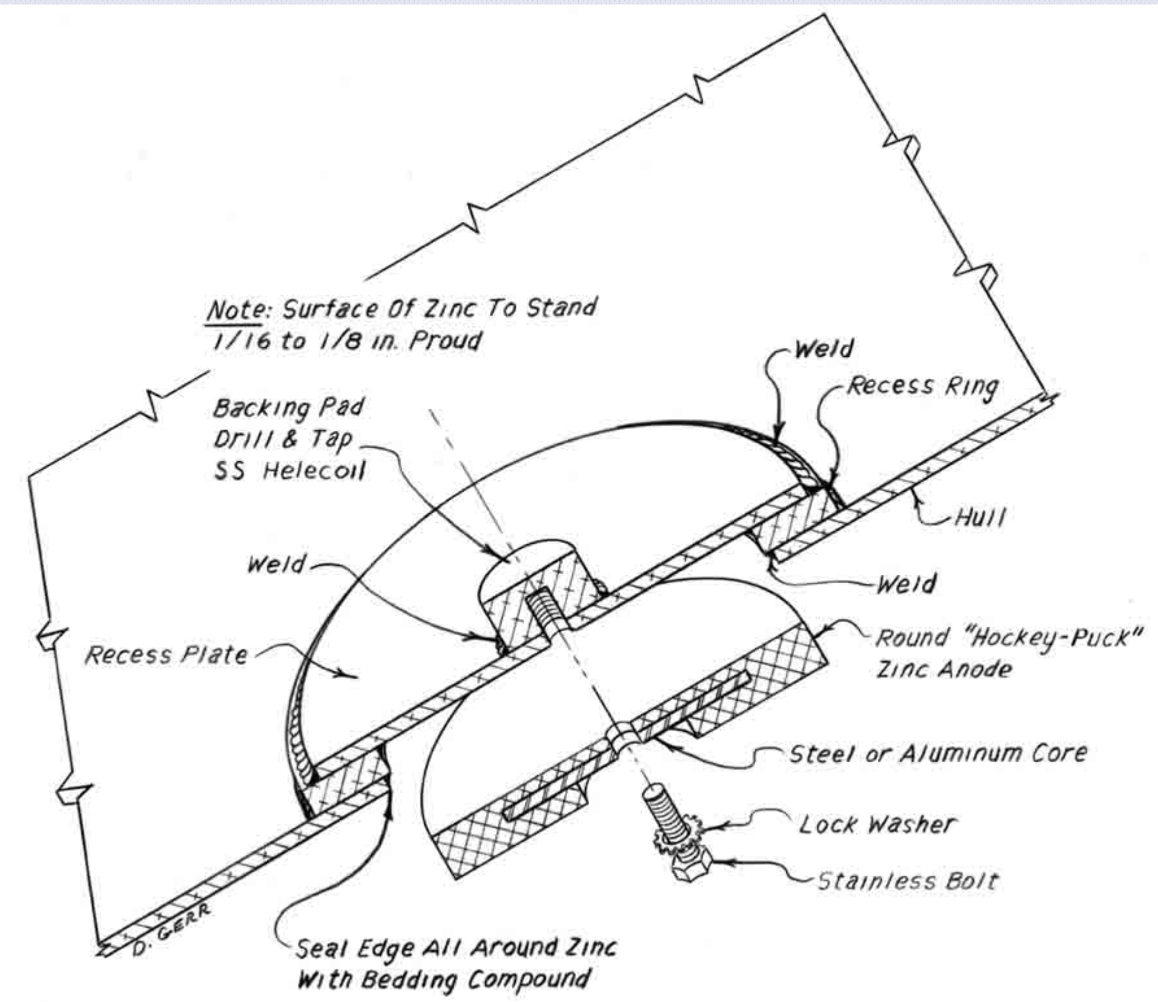
The best method for determining the wetted surface of your hull is to consult the boat's designer. Short of that, however, an estimate sufficiently accurate for sizing zincs can be made from the following formula used by the British corrosion company M.G. Duff:

Hull Wetted Surface (sq.ft.) = LWL (ft.) x (Beam WL (ft.) + Draft (ft.))

Multiply the answer by the following factors for different types of craft:

1.2	cargo vessels, tankers, dredges, and very heavy full-bodied craft
1.0	tugs, trawlers, ferries, heavy motor cruisers, and full-bodied sailing craft
0.75	for medium displacement craft, medium and light lobster boats, average sailing craft
0.5	for very light craft without external keels.

The zincs must be located so they are immersed all or nearly all the time. Usually, they're located on the hull underbody about halfway out between the keel and the turn of the bilge or chine. They must be able to "see" the metal fittings they're protecting.



Low-Drag Recessed Anode