

Taming The Wayward Electron - Part I

Controlling Galvanic Corrosion

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It's a sad but inescapable fact that metals corrode in seawater. Corrosion problems lead to repairs. This adds up to down time and expense. Of course, some metals are more resistant to corrosion than others; but those that corrode least almost invariably cost most. Worse still, even highly corrosion resistant metals, like silicon bronze, 316 stainless steel, Monel, and Aquamet alloys, can corrode or cause other metals to corrode if they're all attached to the same hull underwater. Accordingly, it pays dividends—literally—to spend the time and money needed to understand and control corrosion before it starts controlling you.

Vagabond Electrons are at the Root of Corrosion

The cause of the vast majority of corrosion is electrons that won't stay put. They leave their home metal to travel through any convenient conductor to other metals that keep a tighter hold on their own electrons. To make matters worse, the missing electrons leave positively-charged particles (ions) on the surface of their home metal. These ions react with negatively charged ions in seawater to dissolve away. Such metals—metals that hold loosely to their electrons—are generally quick to corrode. They are referred to as *anodic*, *less noble*, or *active* metals. (Aluminum, mild steel and zinc are anodic metals.) Metals that retain their electrons tightly are called *cathodic*, *noble*, or *passive*. They are generally slow to corrode. (Silicon bronze, stainless steel, titanium and gold are cathodic metals.)

The Potential for Corrosion

Now, when you connect two different metals together electrically and through an electrolyte (in our case seawater), the electrons from the less-noble (anodic) metal will try to tumble towards the more-noble (cathodic) metal. This flow of electrons generates a real measurable force, exactly as you could measure the force in a stream of water flowing through a pipe, from, say, a tank with a high water level (the anode) to one with a low water level (the cathode). Where electrons are concerned, the force of flow is measured not in pounds, but in *volts*, and is often referred to as *potential*. (It's called potential because it measures how great a potential there is for a flow to occur—flow or current in *amps*.)

The Galvanic Series

Of course, potential is relative. Mild steel holds onto its elec-

trons only somewhat more strongly than does marine aluminum. If these two materials were in contact in seawater, the aluminum would corrode (too fast by half), but not nearly as fast as if the aluminum were in direct contact with, say, silicon bronze. Silicon bronze—relatively speaking—holds more tightly to its electrons than does mild steel, and much more tightly still than does marine aluminum.

The key word here is "relative," and the best way to keep tabs on these relative potentials is by listing the voltages of all materials with reference to a single test metal (electrode), in the electrolyte that you're concerned about—seawater for our purposes. (The most stable and sensitive electrode material for this use is silver/silver-chloride—Ag/AgCl). The list of relative potentials generated this way makes up *the galvanic series*, see next page. (Electrical activity increases with temperature, so this is specified as well. Standard galvanic tables usually give voltages at 77 F°.)

Corrosion Misnomers

Or

What's in a Name

There's considerable confusion about the proper name for *galvanic corrosion*—the only correct term. Frequently it's called *electrolysis*, or *electrolytic corrosion*. Both are misnomers. Electrolysis is the corrosion or chemical breakdown of the electrolyte—the fluid medium that transfers ions between metals. Obviously, in our case, electrolysis would be breakdown of seawater itself—not much of a concern. Electrolytic corrosion is the corrosion produced by externally generated electric currents. It's also known as *stray-current corrosion*. Stray-current corrosion can be very serious. It's a vast subject in itself, however, and will have to wait for a future article.

Selecting Fittings Using the Galvanic Series

There are two critically important uses for the galvanic series. First, you should refer to it when installing hardware. *Try to make sure the voltage difference between any two metals, in direct contact in seawater, is less than 0.20 volts or 200 millivolts (mV).* Metals that are less than 200 mV apart corrode each other fairly slowly and need little additional protection. If you must use two metals in contact, further apart than 200 mV, you need to take steps to

protect them, either by insulation (so they're not really in contact) or by using anodes.

Anodes Protect by Flooding with Electrons

There's a nice feature about anodic metals—if you use them wisely—as long as they're losing electrons, all the other more-noble (more-cathodic) metals they're connected to are protected from corrosion. Say, for instance, your *Dry Roller* had a stainless-steel shaft, with a manganese-bronze propeller. Its bronze prop's electrons would be tumbling toward the more-noble stainless. *Roller's* prop would waste away. If a zinc anode were attached to the shaft, its electrons would—roughly speaking—tumble toward both the stainless and the bronze (it's far more anodic than both). It would flood the system with zinc electrons—again, roughly speaking. (Other

Wayward Electron/Galvanic Corrosion Continued . . .

The Galvanic Series

ANODIC OR LEAST NOBLE END (Active)	Millivolts (mV)
Magnesium (Mg)	-1730
Magnesium (2% Manganese (Mn))	-1670
Magnesium (9%Aluminum (Al), 1% Mn,1.5% Zinc (An))	-1580
Galvanized Iron (hot dipped)	-1140
Zinc Electroplating	-1130
Cadmium (Cd) Zinc Solder (71%/29%)	-1120
Zinc (Zn)	-1050
Cadmium (Cd)	-860
Cadmium Plated Steel (Cd 0.001 in.)	-860
Aluminum (Marine Alloys 5086, 5083, 6061)	-820
Mild or Structural Steel(A36)	-790
Alloy Steel	-740
Aluminum (forged alloy)	-730
Stainless Steel (316,317,321,347,302,304 – active, oxygen starved)	-550
Tin (Sn)	-500
Manganese Bronze, CA-464 Naval Brass (58%Cu,39%Zn,1%Alum,0.25%Mg)	-450
Naval Brass (60% Copper, 39% Zinc)	-450
Yellow Brass	-450
Admiralty Brass (70% Copper, 29% Zinc)	-360
Copper CA-110 (Cu)	-340
Brass (60% copper, 40% zinc)	-330
Gunmetal (88% Copper, +Tin)	-310
Silicon Bronze (96% Copper, 1.5% Silicon)	-260
Tin Bronze	-260
Lead (Pb)	-240
Copper/Nickel (CA-715 - 70% Cu, 30%Ni)	-200
Aluminum Bronze (90% Copper, 10% aluminum)	-150
Stainless Steel (316,317,321,347,302,304 – passive, oxygenated)	-150
Monel 400 & 500	-110
Titanium (Ti)	-100
Silver (Ag)	-80
Graphite and Carbon Fiber (C)	(+250)
Platinum (Pt)	(+260)

CATHODIC OR MOST NOBLE END (Passive)

Millivolts (mV)

- All measurements taken relative to a silver/silver chloride (Ag/AgCl) electrode, at 77° F.
- The sign of potential applies with the negative (black) probe of the voltmeter connected to the reference electrode, and positive (red) terminal connected to the fitting being tested
- If using a zinc reference electrode, add 100 mV to the potential. For instance, silicon bronze is - 260mV, then + 100 mV = -160 mV.
- Average variability of potential is ±40 mV for alloys with iron and/or nickel. ±20 mV for copper-based alloys without nickel.
- Readings 200 to 400 mV more negative (more anodic) than given indicate the material is protected.
- Readings at or near those given, up to 200 mV above those given, indicate the material is unprotected and freely corroding.
- Readings over 400 mV more negative than given indicate overprotection.
- Stray current corrosion is indicated by metals reading more cathodic (more positive) than indicated on the table.

Wayward Electron/Galvanic Corrosion Continued . . .

anodic metals such as magnesium and aluminum, are occasionally used as anodes. Zinc, however, offers the best trade-off between cost, reliability and ease of manufacture. It's the standard marine-anode material for use in seawater.)

Passive & Active

The Mysterious Behavior of Stainless Steel

Stainless steel appears in two locations on the galvanic scale—one quite noble, and the other fairly anodic. The key to this mystery is oxygen. Most corrosion-resistant marine alloys protect themselves—to varying degrees—by forming a thin surface-layer oxide film. This is produced by interaction with the oxygen dissolved in seawater. Bronze, Monel, copper and copper-nickel will corrode slightly faster if they lose this film, but will still remain highly corrosion resistant.

Stainless steels, on the other hand, rely chiefly on this oxide film to protect them from corrosion. When stainless is in clean flowing water containing plenty of oxygen it has no difficulty generating and retaining the oxide film. In this condition it's highly cathodic (noble)—a state that's also called *passive*. Should stainless be deprived of a regular supply of oxygen, however—for instance, pressed for a long time, immobile, against a cutlass bearing; smothered by barnacles; or enclosed in a stern tube—it can lose its protective oxide film. In these conditions stainless becomes nearly as anodic as mild steel. Stainless is called *active* in this state, and can suffer severely from pitting corrosion.

Self Destructing Metals

It's not always necessary to have two different metals in contact to get corrosion. Some alloys actually have corrosion potential built in. The ever-popular manganese bronze is a case in point. It's 58% copper and 38% zinc—not really a bronze at all but a brass! Brasses are bad news for use below the waterline because the zinc in all brass is eaten away by the more noble copper. This process is called *dezincification*. Manganese bronze's popularity is due to its ease of manufacture, relatively low cost, and moderately good strength. The dezincification (really internal galvanic corrosion) can be controlled with anodes. Many other alloys suffer from similar problems. Aircraft-grade aluminum alloys, some high-strength steels and all the brasses have alloy combinations which add up to trouble in saltwater.

Checking Potential (Voltage) to Detect Corrosion

This brings us to the second critical use of the galvanic series. As long as zinc electrons are flooding the other metals, it effectively stuffs them with excess electrons. Rather than lose their own electrons and corrode, the excess zinc electrons are lost first, to be replaced with still more zinc electrons, for as long as there's zinc available. These extra electrons change the charge or potential of the protected met-

als. And—since electrons have negative charge—the protected metals become more negative. (Metals that are anodic have more excess or easily freed electrons than cathodic metals. Anodic metal thus read more negative than cathodic metals on the galvanic series.)

This process is called *polarization*. It's a change in potential that can be measured using a portable voltmeter. As long as the measured voltage increase is between -200 to -400 mV (-0.20 to -0.40 volts) above the indicated "normal" voltage or potential shown on the galvanic series, the metal has been polarized enough to be protected from corrosion. Using this information, you can spend an afternoon going 'round your *Dry Roller* testing potentials (polarization or voltages) of various fittings and components to see if they're protected (potential raised -200 to -400 mV) or freely corroding (potential less than -200 mV above the voltage indicated on the galvanic series). It's a good idea to schedule such a test once or twice a year as part of *Dry Roller's* routine maintenance, along with engine overhauls and bottom cleaning.

Using a Voltmeter (Multimeter) to Test for Polarization

The procedure is as follows: You need a quality voltmeter (really a multimeter) with a with at least one scale that can be set to read with a maximum of 1200 to 1500 millivolts (mV, or 1.2 to 1.5 volts); a silver:silver-chloride electrode; and long wire to connect it to the voltmeter. Aboard *Dry*



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Roller, chuck the electrode (connected to the voltmeter, of course) overboard and go below with the meter, touching the free probe end to the fittings you want to test. Make a table listing *Dry Roller's* equipment and fittings and their locations, or make a schematic drawing, labeling the metal fittings to be tested. Note the measured voltages next to each fitting. If you touch the probe to, say, *Dry Roller's* manganese bronze stuffing box and it reads -655 millivolts, it's well protected. On the other hand, if its stainless prop shaft reads -162, it's freely corroding away (it's certainly not connected to any zincs.)

Two sources for test meters, electrodes, and information on corrosion are:

Electro-Guard, Inc.
P.O. Box 1719
Mount Shasta, CA 96067
Telephone: (530) 926-4000
e-mail:
Information@boatcorrosion.com
techsupport@boatcorrosion.com

Sterling Power Products Ltd
Site 8 Wassage Ways
Hampton Lovett Industrial Estate
Droitwich England WR9 0NX
Telephone: 01905 771 771
Fax: 01905 779 434
www.sterling-power.com

Overprotection

It is possible to have too much of a good thing. While you're testing, you should also note whether the potentials have been raised more than -400 millivolts over their "natural" state. Such high potentials mean *overprotection*. If you touch the probe to, say, *Dry Roller's* silicon bronze rudder shaft and get a reading of -807 millivolts, you're showing well over the recommended increased potential. Though generally not as serious as uncontrolled galvanic corrosion, overprotection should be eliminated as quickly as possible.

On traditional wood-hull vessels in particular, overprotection can create alkaline byproducts that literally destroy the lignin holding wood fibers together—a condition known as *alkali rot*. Look for whitish or yellowish foamy, soapy gunk around metal fittings on wood hulls. This is a sure sign of alkali rot. Even on FRP, steel and aluminum hulls overprotection can cause gas bubbles, destroy paint, generate alkaline solutions that actually eat away aluminum, and lead to hydrogen embrittlement of high-strength steels.

Military Zinc

Another thing to keep in mind is that all zincs are not created equal. Make very certain the zincs you buy and install on your *Dry Roller* are intended for marine corrosion protection. There are many common zinc alloys which are useless

for this, yet occasionally they end up on the market as zinc anodes. It should say in writing somewhere that the zincs you purchase meet military specification, or Mill Spec, Mil-A-18001-J or -K (or higher final letter). If you don't insist on zincs to this Mil Spec, you're truly buying a pig in a poke. Almost all reputable suppliers will be glad to meet this requirement. In fact, they'll boast of it in their advertising.

Characteristics of Mil-Spec Zincs

Specific Gravity	7
Density	440 lb./cu.ft.
Theoretical Ampere-Hours/Pound	372
Theoretical pounds/Ampere-Year	23.5
Current efficiency in actual average installations	90%
Actual Ampere-Hours/Pound	335
Actual pounds/Ampere-Year	26

Composition:

0.005% copper, 0.005% iron, 0.006% lead, 0.025 to 0.070% cadmium, 1 to 5% aluminum and the balance zinc.

Most marine hardware stores carry Mil-Spec zincs, however, three sources for quality Mil-Spec zincs are:

West Marine
www.westmarine.com

W.H. Den Ouden Vetus (USA) Inc.
www.vetus.nl

Defender Industries
www.defender.com

In the next article we'll take a detailed look at determining the amount of zinc you need and at how your anodes should be installed. We'll also discuss the bonding system and refinements like zinc controllers and monitors. You'll want to hold onto this issue, as the galvanic series and potential-testing method we discussed here will be useful next issue—and, of course, whenever you plan to check for corrosion.

