Corrosion Control

Undetected bonding circuit problems can lead to costly and time-consuming repairs.

By Sue Canfield

The potential for galvanic and stray current corrosion is a fact of life for many boats, especially those that operate in seawater. Galvanic corrosion can occur whenever a boat's dissimilar underwater metals are electrically connected, whether by direct contact, a wire conductor, or even an opportune conductor like bilge water. Differences in the inherent electrical potential of dissimilar metals in seawater, typically measured in millivolts (mV) (see **Figure 1**), will generate low-level currents. These currents will gradually -- over a period of months or years -- erode the least noble metal (anode) while protecting the more noble metal (cathode). Stray current corrosion is induced by the leakage of higher levels of current, from an external electrical source, through a boat's underwater metal fittings. Stray current (DC) is like galvanic corrosion on steroids; it can destroy underwater metals in a few weeks, days, or even hours.

A proper bonding system, one that electrically ties together all of your boat's metals in contact with the water, will prevent corrosion damage due to self-generated galvanic and stray current. It will not prevent damage due to galvanic or stray current coming from sources outside your boat. That requires measures that are beyond the scope of this article.

In a bonding circuit installed solely for corrosion control, the interconnected metals are protected by one or more sacrificial anodes typically made of zinc, although magnesium and even aluminum anodes are sometimes used. On most boats, this corrosion protection circuit is part of a larger bonding system connected to the engine negative terminal or its bus. This system typically includes other major metal objects onboard: rigging and chainplates, engines, metal tanks, metal cases on electrical equipment, etc. By providing a low-resistance electrical path to ground, a proper bonding system prevents the buildup of voltage differences between otherwise isolated metal objects. It also minimizes stray current corrosion.

A bonding system, however, is only as good as its conductors, connections and sacrificial anodes. If a low-resistance electrical path is not maintained, galvanic and stray current corrosion can occur. If the anodes supply too little voltage, bonding will actually promote corrosion by providing the electrical connection needed for galvanic current to flow.

Checking System Continuity

To insure a low resistance current path, bonding circuit conductors should be at least #8 AWG insulated stranded copper or, if copper tubing or strips are used, have a minimum thickness of 1/32 inch (0.8 mm) and a minimum width of ½ inch (13 mm). Per ABYC, insulated conductors should be green, or green with a yellow stripe. Check for bonding system continuity while your boat is blocked ashore or sitting on its trailer. After setting your multimeter to measure ohms, just touch the probes to any two metal fittings tied into the bonding circuit, e.g., the propeller and the zinc anode on the propeller shaft, the rudder stock and an adjacent through-hull fitting, etc. All readings should be electrically perfect, i.e., 1 ohm or less. If not, check for damaged conductors and loose or corroded

connections at the affected fittings. Make repairs as needed, and re-test. Once your boat is back in the water, the electrical current produced by dissimilar underwater metals will make continuity readings impossible.

Checking System Performance

After you've launched your boat, you can avoid potentially costly and time-consuming repairs by checking bonding system performance at regular intervals. Hire a marine surveyor or marine electrician to do a corrosion control survey for you, or save money by doing it yourself. In the latter case, you'll need an analog corrosion test meter or a good quality digital multimeter, and a silver/silver chloride (Ag/AgCl) reference electrode. Reference electrodes, stable mixtures of a metal and metallic salt, are often called half-cells. They function as one electrode in an electrochemical cell when measuring the electrical potential of other metals. See **Figure 2** for equipment sources and prices. A multimeter with high input impedance will allow you to test your boat in either fresh or saltwater with repeatable results.

You'll also need paper and a pen to record your test data. Start by listing all the underwater metal fittings (those that are accessible from inside the hull) that are or should be included in your boat's bonding circuit, e.g., through hull fittings, transducers, engines, strainers, propulsion and rudder shafts and logs, sacrificial anodes, etc. Don't worry if you forget some, you can add them later as you move through the boat.

Next, unplug your boat's shorepower cord (if any) and disconnect your batteries. If you'll be using a multimeter, set the function switch to DC volts. Connect the reference electrode to the volts input jack. Lower the electrode over the side until it's a foot or more below the water's surface. You'll get more reliable readings if the electrode is near not immediately next to the fittings being tested. If necessary, tape the lead to the toerail or tie it to a nearby stanchion so you won't pull the electrode out of the water as you move through your boat. Connect the test probe you'll be using to contact each underwater metal fitting to the multimeter's common jack.

Starting at one end of the boat and working toward the other, take a voltage reading at each metal fitting. If the lead on the reference electrode is too short to allow you to reach all of your boat's underwater fittings, buy or fabricate an appropriate extension.

As shown in **Figure 3**, analog corrosion meters typically display all millivolt readings as positive values and indicate the degree of protection for bronze, steel and aluminum. If you're using a digital multimeter to test your boat's bonding system, you may want to keep a copy of **Figure 4** handy for quick reference.

The voltage at all bonded underwater hardware should be the same. If not, check for damaged bonding conductors and loose or corroded connections at the affected fittings. Make repairs as needed and re-test. How much zinc does your boat need? Enough to maintain a minimum negative shift of 200 mV relative to the potential of the least noble metal being protected (see **Figure 1**). If the voltage shift is less than 200 mV, add more zinc. Allow for normal wastage during the boating season. Keep in mind that overprotection can create problems too, especially for wood or aluminum boats.

Be sure to write down the voltage reading for each fitting. You'll want to keep a copy of the data you collect with your boat's maintenance records for future reference.

Checking for Stray Current

Next, reconnect your batteries and turn on each DC circuit, one at a time. Check the voltage at any bonded fitting as each circuit is activated. Make sure that the equipment controlled by the circuit is turned on as well. If the voltage reading changes, stray current is leaking into the bonding system, either from the DC circuit's wiring or the equipment it serves. Turn the circuit turned off until you can track down and eliminate the problem. As needed, hire a qualified marine electrician to help you.

Finally, plug in your boat's shorepower cord. If doing so produces a sustained change (not just a pulse) in the voltage reading at any bonded fitting, current is leaving or coming onboard via the cord's green grounding wire. To correct this problem, you'll need to install a galvanic isolator or isolation transformer (see DIY 2001 #4). Now check the voltage at any bonded fitting as each AC circuit is activated. Again, make sure any associated equipment is turned on as well. If there's a sustained change in the voltage reading, stray current is leaking into the bonding system from the AC circuit that has just been turned on. Since alternating currents are equal and opposite, stray AC current theoretically causes little corrosion. That's the good news; the bad news is that it poses a potentially lethal electrical shock hazard. Keep the shorepower cord unplugged until you can track down and eliminate the problem. As needed, hire a qualified marine electrician to help you.

How often should a bonding system be checked? At least annually, after moving to a new (permanent) slip, or whenever there is accelerated wastage of the sacrificial anodes on your own or neighboring boats.

Equipment Suppliers:

- The Guest Co., Inc. - 95 Research Parkway, Meriden, CT 06450; 203-235-4421; www.guestco.com
- Professional Mariner, LLC - P.O. Box 968, Rye, NH 03870; 603-433-4440; www.pmariner.com
- US Filter Electrocatalytic/Electrode Products - 2 Milltown Court, Union, NJ 07083, 800-553-5228, www.usfilter.com

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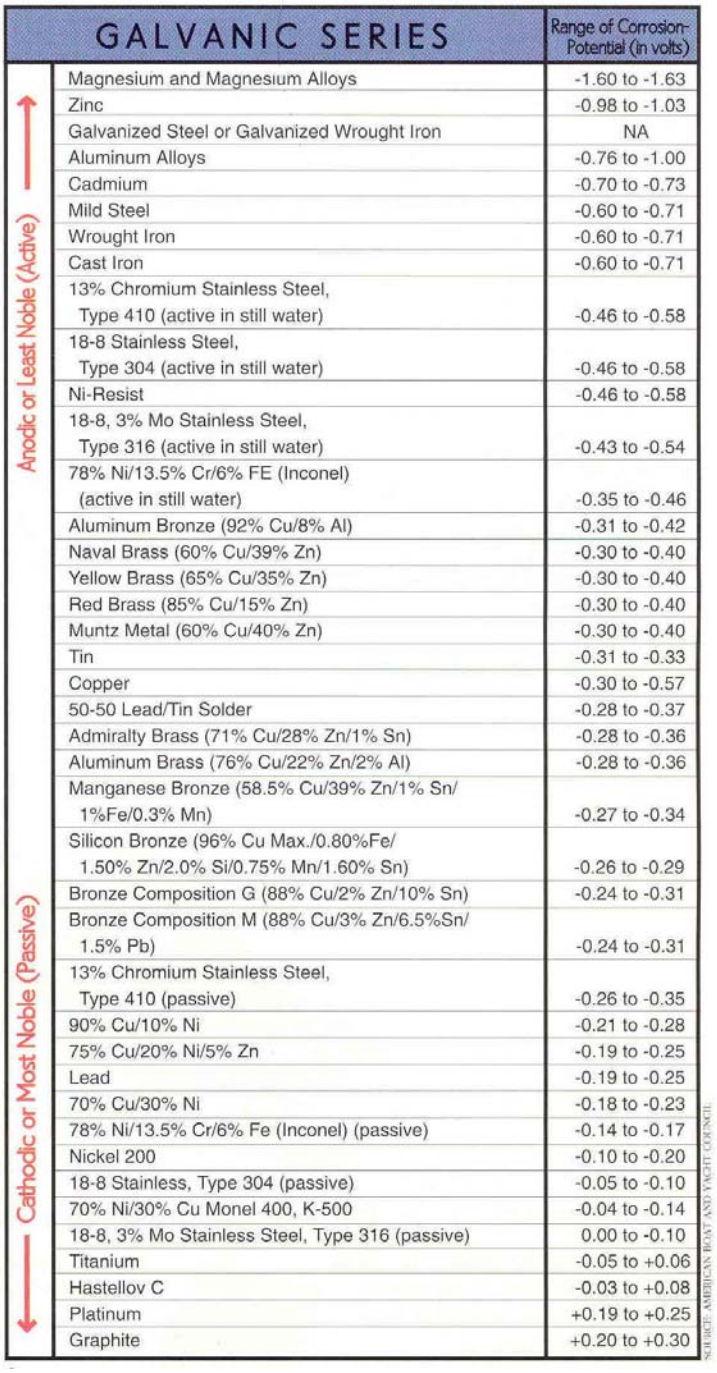

GALVANIC SERIES	Range of Corrosion-Potential (in volts)
Magnesium and Magnesium Alloys	-1.60 to -1.63
Zinc	-0.98 to -1.03
Galvanized Steel or Galvanized Wrought Iron	NA
Aluminum Alloys	-0.76 to -1.00
Cadmium	-0.70 to -0.73
Mild Steel	-0.60 to -0.71
Wrought Iron	-0.60 to -0.71
Cast Iron	-0.60 to -0.71
13% Chromium Stainless Steel, Type 410 (active in still water)	-0.46 to -0.58
18-8 Stainless Steel, Type 304 (active in still water)	-0.46 to -0.58
Ni-Resist	-0.46 to -0.58
18-8, 3% Mo Stainless Steel, Type 316 (active in still water)	-0.43 to -0.54
78% Ni/13.5% Cr/6% FE (Inconel) (active in still water)	-0.35 to -0.46
Aluminum Bronze (92% Cu/8% Al)	-0.31 to -0.42
Naval Brass (60% Cu/39% Zn)	-0.30 to -0.40
Yellow Brass (65% Cu/35% Zn)	-0.30 to -0.40
Red Brass (85% Cu/15% Zn)	-0.30 to -0.40
Muntz Metal (60% Cu/40% Zn)	-0.30 to -0.40
Tin	-0.31 to -0.33
Copper	-0.30 to -0.57
50-50 Lead/Tin Solder	-0.28 to -0.37
Admiralty Brass (71% Cu/28% Zn/1% Sn)	-0.28 to -0.36
Aluminum Brass (76% Cu/22% Zn/2% Al)	-0.28 to -0.36
Manganese Bronze (58.5% Cu/39% Zn/1% Sn/ 1%Fe/0.3% Mn)	-0.27 to -0.34
Silicon Bronze (96% Cu Max./0.80%Fe/ 1.50% Zn/2.0% Si/0.75% Mn/1.60% Sn)	-0.26 to -0.29
Bronze Composition G (88% Cu/2% Zn/10% Sn)	-0.24 to -0.31
Bronze Composition M (88% Cu/3% Zn/6.5%Sn/ 1.5% Pb)	-0.24 to -0.31
13% Chromium Stainless Steel, Type 410 (passive)	-0.26 to -0.35
90% Cu/10% Ni	-0.21 to -0.28
75% Cu/20% Ni/5% Zn	-0.19 to -0.25
Lead	-0.19 to -0.25
70% Cu/30% Ni	-0.18 to -0.23
78% Ni/13.5% Cr/6% Fe (Inconel) (passive)	-0.14 to -0.17
Nickel 200	-0.10 to -0.20
18-8 Stainless, Type 304 (passive)	-0.05 to -0.10
70% Ni/30% Cu Monel 400, K-500	-0.04 to -0.14
18-8, 3% Mo Stainless Steel, Type 316 (passive)	0.00 to -0.10
Titanium	-0.05 to +0.06
Hastelloy C	-0.03 to +0.08
Platinum	+0.19 to +0.25
Graphite	+0.20 to +0.30

Figure 1 *– The galvanic series of metals in seawater (relative to a Ag/AgCl reference electrode) flowing at 8 to 13 feet/second and at a temperature range of 50-80ºF. In general, the greater the difference in electrical potential between two connected underwater metals, the greater the likelihood for galvanic corrosion. Actual corrosion rates are the product of many factors, including the exposed surface area of the metals, the conductivity and flow rate of the electrolyte, etc. (Professional Boatbuilder, Dec/Jan 1995)*

Corrosion Test Equipment		USD
Guest	Analog meter, Ag/AgCl reference electrode on 20' lead, 10' test lead with clamp (#2434)	$210
	Ag/AgCl half cell on 10' lead (#2435)	$70
Professional Mariner	Analog meter, Ag/AgCl reference electrode on 20' lead, 10' test lead with clamp (#20086)	
	Ag/AgCl reference electrode on 20' lead (#20008)	$169
	20' red lead extension (#20009)	$33
	10' black test lead with clamp (#20007)	$33
	Corrosion Workbook (#20001)	$50
US Filter	CAPAC analog meter, Ag/AgCl reference electrode on 75' lead (#33419)	$760
	Ag/AgCl reference electrode on 75' lead (#33428)	$225

Figure 2 *- If you own a good quality digital multimeter, you can buy everything else you'll need (highlighted blocks) to monitor your boat's bonding system for $100-$130. Listed prices for Guest products were taken from West Marine's 2003 catalog. All other prices are for direct purchase from the manufacturer. Prices available through Professional Mariner distributors may be lower than those listed, e.g., West Marine lists the Corrosion Workbook (#542217) in its catalog for just $30.*

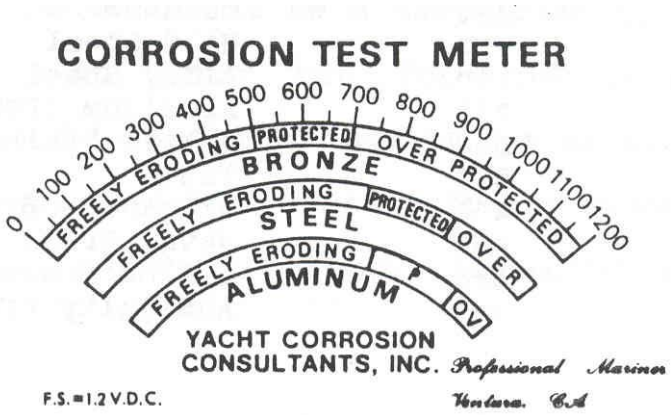

Figure 3 *- Analog meters like those sold by Professional Mariner and Guest provide direct read out of the degree of protection for bronze, steel and aluminum. (Professional Mariner)*

Metal	Degree of Protection/Millivolts			
	Freely Eroding	**Protected**	**Overprotected**	**Damage***
Bronze	<500	500 -700	>700	>1250
Steel	<750	750 -950	>950	>1200
Aluminum	<800	800 -1050	>1050	>1200

*** To metals and/or paint coatings**

Figure 4 *- If you use a digital multimeter to test your boat's bonding system, keep a copy of this table handy for quick reference.*