

# Marine Services

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INTERNATIONAL MARINE CONSULTANTS

ELECTRICAL AND CORROSION CONTROL SPECIALISTS

### BONDING AND CATHODIC PROTECTION OF VESSELS

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The following was written with fiberglass hulls in mind. While some of the information may be applicable to wood and metallic hulls, it was not my intent to address them at this time.

Traditionally, there have been five (5) reasons stated for bonding vessels:

1. A means of providing cathodic protection for the various metallic items on the exterior of the hull.
2. The internal collection of stray direct currents that may find their way into wet bilge areas that contain metallic hull fittings.
3. Lightning protection.
4. Radio noise suppression.
5. Counter poise grounding.

**1.a. CATHODIC PROTECTION BONDING:** The need to bond, for the purpose of providing cathodic protection is based on several factors, such as the composition of the metallic fitting to be bonded, the location of these fittings and the operating area of the vessels, such as fresh or salt water.

Anytime that two (2) or more pieces of underwater metal are connected, touching or bonded, they become anode dependent. When I use the term "anode dependent", I am referring to the fact that once we connect dissimilar metals together, the lowest voltage metal will corrode preferentially, thus becoming an anode. Hence, the need for special anode material. Even though two pieces of metal may be of the same alloy, there will always be a slight voltage difference that will cause galvanic current to flow, resulting in galvanic corrosion of the lowest voltage metal.

When a good grade of bronze is used for a fitting, such as what is commonly used in the USA and known as 5-5-5 bronze, it generally has the ability to withstand corrosion without any cathodic protection. It is usually when we mix the various metals, such as the stainless steel propeller shaft and the bronze propeller, that we encounter corrosion difficulties.

The main bonding conductor should be run well above the bilge level. This conductor should be well insulated. Individual bonding conductors should be a minimum of eight gauge-stranded conductor. Wherever possible, crimped ring connectors should be used. Do not use connection points at individual fittings as if they were a bus. Do not loop (daisy chain) from one (1) fitting to the next. Do not connect through a device, i.e., one (1) wire into a through hull bolt on one (1) side and out a different bolt on the other side. If there is a need for two (2)

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connections on one (1) device, make them on the same bolt. Seal the ring connectors with a material such as liquid electric tape.

Once the decision to bond the vessel has been made, it is extremely important to ensure that an adequate amount (enough to last between scheduled haul-outs) of anode be maintained on the vessel to prevent the corrosion of the next metal on the nobility scale.

**2.a. STRAY DIRECT CURRENT BONDING:** The collection of stray direct current from wet bilge areas is a very valid reason for bonding. Capturing the stray direct currents while they are still inside the vessel and returning them to the negative battery post prevents stray current corrosion of the metallic underwater hardware. Remember, stray current wants to do only one (1) thing, return to its source.

If there is an **UN-BONDED** through hull in the bilge pocket that contains the pump that is leaking direct current, this current will flow to the through hull and out of the vessel. The current will then flow from the through hull to another underwater metal part that is connected to DC negative, in an effort to return to its source, the DC negativity of the battery. In this process, the through hull (any metallic material) can be completely destroyed in as little time as one (1) day or two (2) days, depending on the salinity of the water and amperage.

Normal bonding for cathodic protection purposes provides the additional protection against stray current corrosion, which is also known as electrolytic corrosion.

To aid in the prevention of stray current corrosion, run all conductors well above the bilge level.

**3.a. LIGHTNING PROTECTION BONDING:** While a lightning protection system (bonding system) can be a very important feature, if the vessel is not used in an area prone to lightning strikes, the investment may not be beneficial. To offer lightning protection on a powerboat, a company would have to install an "Air Terminal" at a substantial height above the bridge and a heavy ground wire in a **VERY DIRECT** path to a copper ground plate on the bottom of the vessel. I personally feel that this would be quite expensive for an unknown potential return in the form of safety. This system may be more practical when installed in conjunction with a short wave radio counter poise system. Both systems require far more extensive bonding/grounding than for cathodic protection and stray current control. These systems can be very difficult to install on powerboats because of the need to keep cable runs as straight as possible.

I am unaware of any boat builder that offers a lightning protection bonding system. Many boat builders do not provide any bonding in an effort to shed liability.

A vessel that is well bonded and grounded provides a degree of protection by virtue of the fact that all major metal components are connected, resulting in minimal flash over during a strike. The multiple connections to the water, via the bonded fittings, also help dissipate the lightning current.

**4.a. RADIO NOISE SUPPRESSION:** It was once a common practice to bond virtually every piece of metal in a vessel in order to keep the electrical noise out of the radio equipment. The problem of radio noise has not totally disappeared, however, it is nothing compared to what it once was. The new Hi-Tech electronics, combined with quality electrical equipment and a normal bonding system, have virtually eliminated the noise problem for the average boater. Shaft brushes were usually a part of this system and will be discussed later in this paper.

For those vessels that do experience a noise problem, it is much more cost effective to diagnose the specific noise problem and treat it accordingly. This could entail repairs to existing equipment, rerouting cables or the addition of specialty noise suppression filters, which are readily available.

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**5.a. COUNTER POISE GROUNDING:** The counter poise system consists of a highly specialized grounding network whose sole purpose is to enhance short wave radio/single side band radio communications.

Very few vessels will require this type of grounding system. Large vessels and those that are set up to cruise extensively are the likely candidates. The best systems are those that are **built in** during the construction of the vessel.

Numerous papers have been written on the subject. Gordon West has written several articles and an installation instruction for ICOM.

The grounding conductors usually consist of flat copper strap approximately two (2) inches wide. Large sheets of copper screen are often built into the vessel's fiberglass components. Most large metal components are connected to the system.

After market installations are not recommended unless there is a special need.

**6. ANODES:** The open circuit voltages for anodes and related data:

Zinc – 1.05 vdc or 1050 mvdc	AH/lb	368	99% efficiency
Aluminum – 1.1. vdc or 1100 mvdc	AH/lb	1150	90% efficiency
Magnesium – 1.6 vdc or 1600 mvdc	AH/lb	500	50% efficiency

An anode (anodes) mounted low on the stern (transom) of the vessel is one of the easiest and less expensive methods of providing cathodic protection. Zinc is generally sufficient for cruisers with conventional propellers and shafts operating in salt and brackish waters. Vessels equipped with stern drives (any brand) should use aluminum anodes on the drives and if additional anode material is required, aluminum anodes should also be used. Magnesium anodes should only be used under the strict guidance of a corrosion specialist.

Use only one connection/conductor (#6 GA) from the transom anode(s) to the bonding system. Do not create bonding system loops. Voltage is never the same at any two (2) locations in a loop, resulting in circulating currents. When more than one anode is used, connect all anodes together internally at the mounting bolts.

When using transom anodes, pick a standard size and stick with it. Annual change outs will be much simpler. Depending upon size and materials, a vessel may need two (2) or more anodes to provide sufficient protection between haul outs. If you need new anodes by mid-season, you did not have enough to start with.

Through transom bolts (stainless steel/bronze) for anode mounting should be installed in such a manner that when changing anodes, the connection/seal to the transom is not broken/disturbed.

Given the fact that most stern drives are now equipped with aluminum anodes, it would be a mistake to use a zinc transom anode, because the drive anodes would provide cathodic protection to the zinc anode, resulting in excessive anode loss on the drives and a higher risk of drive corrosion. Aluminum anodes contain more than three (3) times the amperage per/lb than zinc anodes and have more driving potential.

If aluminum anodes are used, I would suggest those produced in the United States by Performance Metals in Bechtelsville, Pennsylvania (phone: 1-877-612-5213). Performance Metals' aluminum anodes meet the US Navy Military's Specification ( MIL-A-24779 (SH) ) and are suitable for all stern drives and most other marine application. The aluminum anodes were developed to produce increased protection and provide better self-cleaning in fresh water situations and they perform very well in salt water.

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When using zinc, always use US Navy Mil Spec Zinc Anodes. Do not use “Electro Guard” anodes. Those anodes do not contain cadmium, which is a necessity for proper performance of the anode.

There are a couple of devices on the market, such as “Zinc Positive” and “Gimic” that allow you to insert a zinc into a hose with the stated purpose of protecting everything downstream. These devices do not work and cannot be made to work.

Extensive testing of these types of devices by Mercury Marine and others proved conclusively that they are virtually ineffective. The zincs will however corrode, giving the impression that the devices are performing as advertised.

*NOTE: Anodes should be replaced on an annual basis, especially in fresh water. Zinc anodes can become completely inactive in as little as two (2) to three (3) months in fresh water. It is extremely important that yard personnel be able explain this need to boaters. Once an anode is covered with insulating film, it is essentially useless. It is often very difficult to convince a boater that the yard is not trying to rip them off for a new set of anodes, given the fact that their anodes still look new. Instruct yard personnel in the use of an OHM meter so they can show customers that the crud on the anode surface is actually an insulation layer that renders the anode useless.*

**7.a. SEA-COCKS AND SEA-STRAINERS:** Sea-cocks come in a variety of types, the old traditional type of “tapered plug valve” that is all cast bronze is quite resistant to corrosion without any cathodic protection as are the rubber plug valve types. Other types of sea-cocks, which contain chrome/stainless, steel balls and brass stems with brass bodies **MUST** be cathodically protected.

From a pure cathodic protection standpoint, it does not make sense to bond internal fittings such as sea strainers. Cathodic protection for items that are connected by hoses is unnecessary and virtually impossible to provide because cathodic protection current in a hose is only effective for a distance of approximately 2/3 times the diameter of the hose in question.

**8. THROUGH HULL LOCATIONS:** Some boat builders bond all through hull fittings regardless of location. Fittings that are not submerged, such as those on the side of the boat, do not receive any benefit from being bonded. It is a waste of time and material to bond such fittings.

**9. PROPELLER/SHAFT PROTECTION:** Propellers and shafts are easily and economically protected by individual anode collars on the propeller shafts. Single shaft collar anodes should be located close to the propeller end of the shaft. Multiple anodes should be spread out over the length of the propeller shaft. Do not install the anodes closer than two (2) to three (3) shaft diameters from the strut bearings in order not to disrupt water flow to the bearing. On a bonded vessel with hull anodes, a small amount of cathodic protection current passes through to the prop/shaft via the engine/transmission bonding connection. This is, however, a very poor electrical connection because contact is made through gears and bearings that are immersed in oil. When underway, the connection is virtually non-existent. Generally speaking, the two anodes per shaft are sufficient with bronze propellers.

When Nibral (nickel, aluminum, bronze) propellers are used it may take three (3) to five (5) anodes per shaft because Nibral is much more difficult to polarize. It is often best to experiment with the number of anodes in the waters where the vessel is normally operated. If possible, install enough anodes to last between haul outs.

Marine shafting is generally provided in three grades: 17, 19 and 22. The two common brands being “Aquamett” and “Sea Shaft”. Sea Shaft” is essentially the same as “Aquamett”. All three (3) grades **MUST** have cathodic protection in salt water. Alloys 17 and 19 are quite satisfactory for those vessels that are operated on a regular basis, such as work and charter boats. If 17 and 19 sit idle for long periods of time, they will start to corrode.

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Alloy 22 is best suited for the pleasure boat industry because of the fact that pleasure boats do sit idle for long periods of time. Alloy 22 is formulated to resist crevice and oxygen deprivation corrosion.

Alloys 17 and 19 should be cathodically protected in all waters. With respect to Alloy 22, any exposure to chlorides (salt water) dictates that the shaft be cathodically protected. If a bronze propeller is used with the Alloy 22 shaft in fresh water, it should be protected. If Alloy 22 is used with a Nibral propeller in fresh water, cathodic protection may be omitted.

However, a drive saver shaft insulator should be utilized to prevent current flow between the shafts.

The common practice (in the field) of installing a ground wire from the forward to the rear half of the metallic shaft coupling is not necessary. The metal contact surfaces provide an adequate electrical connection for cathodic protection and for lightning strike current.

*NOTE: Any anode addition/removal should be based on the valid needs of a particular vessel. The correct galvanic voltages should be verified with a silver-silver/chloride reference electrode and a quality digital voltmeter or high impedance analog voltmeter.*

**10. RUDDERS:** Metallic rudders are best protected by individual anodes. The rudders should, however, be connected to the bonding system. The metallic rudder linkage often provides a weak electrical connection between rudders and DC negative, which is undesirable. If there is any electrical connection, it should be low resistance.

Non-metallic rudders will usually have a stainless steel shaft that is often in the form of a pipe or solid shaft. Even with very little water exposure, cathodic protection is necessary. Cathodic protection is best achieved through the use of a flexible conductor to the bonding system and relying on protection from the hull mounted anode.

**11. STRUTS:** Struts are generally quite easy to cathodically protect by connecting them to the bonding system and utilizing the hull mounted anode. Strut bolts should be of the same alloy as the strut, i.e., bronze with bronze and stainless steel with stainless steel. If the struts are aluminum, 315 stainless steel hardware should be used.

**12. SHAFT BRUSHES:** These brushes are usually made of graphite or oil impregnated bronze bearing material and sell for around \$30.00. These brushes do not work! For any shaft brush to be effective, it must maintain a brush to shaft resistance of less than 0.01 OHMs. This cannot even be measured with a conventional OHM meter. It is not uncommon to find OHM readings that range from one to eighty OHMs. Proper cathodic protection cannot be provided to the prop/shaft assembly via these types of brushes. Stainless steel (shaft) is one of the least conductive metals and when combined with graphite brushes, low voltage and a wet to moist area, the results are completely predictable. It can not and will not work!!

One manufacturer sells a “zinc control” system where one or two anodes are mounted on the transom and the zinc output conductor is run through the controller.

The manufacturer states the necessity for removing all shaft anodes. With this system, all cathodic protection current for the shafts provided through the shafts is provided through the shaft brushes. This is electrically impossible and these systems should be avoided at all cost. The systems are usually marketed by wanna-be corrosion personnel who have read an introductory corrosion publication and have been advised that they are now qualified to conduct corrosion examinations, give advice and install corrosion protection equipment.

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The manufacturer of the low quality zinc controller also had a program where a factory representative would visit a boat builder and explain to them that the majority of shaft vibration problems/complaints were the result of shaft anodes corroding unevenly. Their answer to this bogus problem was to install their shaft brushes and eliminate the shaft anodes. As a result of this effort, several boat builders followed their advice, installed shaft brushes and eliminated shaft anodes.

The use of this type of equipment should be thoroughly discouraged in the vessel owner's manual, as well as encouraging boat owners to seek out personnel with proper training, such as certification by the National Association of Corrosion Engineers (NACE) and the American Boat and Yacht Council (ABYC).

**13. SLIP RING ASSEMBLY:** These devices are available for shafts of 1 3/4" and up and sell for \$600.00 to \$800.00 each. The propeller shafts are wrapped with a sterling silver band and the brushes are approximately 85% sterling silver. These devices are standard equipment on many commercial and military craft. These devices are completely capable of providing all cathodic protection current to the prop/shaft assemblies. While I see little need for these, they work great when there is little or no room for shaft anodes. These devices can also be used for measuring shaft potential at rest and while underway by utilizing a dedicated brush,

**14. SHAFT ISOLATORS:** Shaft isolators/insulators are sold under several name brands. The most popular brand is "Drive Saver". These devices are installed between the propeller shaft half of the drive coupling and the transmission half of the coupling. The drive saver electrically isolates the shaft/propeller from the remainder of the bonding system. When these devices are used, **ALL** cathodic protection from the bonding system ceases and protection must be provided by shaft anodes or via a slip ring assembly. In addition to electrically isolating the shaft from the engine, the device also allows for slight misalignment between the shaft and the engine.

**15. PROPELLERS:** When propellers are turning at about 150 RPM without or with inadequate cathodic protection, the blade tips become anodic to the propeller hub. There is about 100-mvdc differential at 150 RPM and this differential will continue to increase as the propeller speed increases. The end result is blade tip galvanic corrosion. With bronze propellers, the zinc in the blade tip is consumed, leaving a copper rich alloy that is very brittle. The blade tip will have a serrated rosy copper rich appearance. This condition is often confused with and referred to as cavitation corrosion. The blade tip corrosion problem is also commonly and erroneously referred to as electrolysis (see #21). Nibral propellers do not contain zinc and are far more corrosion resistant than bronze propellers.

**16. TRIM TABS:** The majority of trim tabs used are constructed of 304 stainless steel (SS) with a 2B mill finish. This grade of SS is highly susceptible to galvanic corrosion and will not stand up well to a salt water environment unless it is cathodically protected. The trim tab should be externally bonded with a stainless steel wire to the transom hinge plates at one of the mounting screws. Each trim tab should have one rudder zinc attached to it. A 2" or 3" anode should be sufficient. Local conditions may dictate the need for increased amounts to last between haul outs. Trim tabs should not be connected to the internal bonding system. Trim tabs should be painted to reduce anode consumption.

**17. AC/DC CROSS CONNECT:** In conjunction with the bonding/grounding system, it is absolutely necessary for safety reasons to provide a conductor between the AC grounding bus and the DC negative bus. This cross connect conductor insures a low resistance internal electrical path for alternating stray current to depart the bonding system.

If stray current (AC) was present on the bonding and the cross connect conductor was not installed, this AC would exit the vessel via bonded metallic hull fittings, resulting in a very serious shock hazard.

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**18. AC NEUTRAL TO AC GROUNDING CROSS CONNECT:** The AC neutral (grounded) (white) system must remain separated from the AC grounding (green) system by 25,000 OHMs. Connections between these systems can eliminate/bypass the galvanic isolation of the vessel and pose a serious shock hazard.

**19. IMPRESSED CURRENT CATHODIC PROTECTION (ICCP) SYSTEMS FOR STERN DRIVES:** These systems are extremely important as they perform the same function as an anode. The only difference is that they do it electrically. Mercury Marine has stated that all stern drives should have these systems (Mercathode) installed as standard equipment in the near future.

These devices are available in two (2) forms, one (blue controller) that is an integral part of the drive and one (black controller) that mounts on the transom and can be used with any make of stern drive.

These devices are lightweight, compact, simple, effective and relatively inexpensive. They are designed to produce approximately 200MA of direct current when operated in salt water and approximately 25MA in fresh water. Their output amperage can be increased by additional Mercathode anodes on the stern. In salt water, the output amperage can be increased by adding an additional controller in series with the original. The limiting factors are the size of the anode in fresh water and the 200MA output of the controller in salt water. Mercury Marine provides complete instructions for the modifications of these systems. A red controller that has a 400MADC capacity is available as a replacement for the blue controller.

When impressed current systems are used in conjunction with shore power, it is extremely important to galvanically isolate the vessel. The most practical and least expensive way to do this is with a UL listed galvanic isolator. For a detailed discussion of isolators, please see my letter to Tom Hale at ABYC.

When impressed current systems are used with anodes, the system will not produce protective current until the anodes have corroded to the point that the voltage starts to increase (more positive). At this point, the system starts to provide protective current and will increase its output as the anodes are depleted.

*NOTE: The Mercury ICCP Systems have been plagued with numerous problems. However, when they are operational, they perform quite well and maintain the hull potential at  $-1.0\text{VDC}$ .*

*NOTE: The Volvo ICCP System has had major problems since its introduction. These systems can drive the hull potential down to  $-4.5\text{VDC}$ , destroying the drives in a very short period of time.*

**20. IMPRESSED CURRENT SYSTEMS FOR METAL HULLS:** At least two (2) companies manufacture systems that cover the range from thirty-foot vessels to ships that are hundreds of feet long.

The most common systems are produced by Electro Catalytic, located in Union, New Jersey. The other company is Electro-Guard, located in Grass Valley, California.

Systems from the above are capable of providing complete hull and hardware protection or they can be used for specific applications only, such as for the propellers and shafts.

**21. ELECTROLYSIS:** The term electrolysis is, without a doubt, the most confusing and misused term in the corrosion vocabulary. It is a term, which technically has no meaning in a marine context. The term actually refers to the degradation of an electrolyte that occurs as a result of passing electrical current through it.

This term is in widespread usage and is generally used to erroneously describe any and all types of marine corrosion. The American Boat and Yacht Council (ABYC) E2 – Cathodic Protection Standard, dated 07/01 with a compliance date of 07/31/02, should be consulted with performing this type of work.