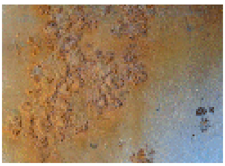
White Paper

CORROSION | ELECTROLYSIS | BLISTERING

CATHODIC PROTECTION OF PLEASURE BOATS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INTRODUCTION

Carefully study the hulls, keels, sterndrives, shafts, propellers, etc. of many leisure boats on dry land during careening or when laid up for winter, and look out for the more or less evident visible symptoms on the cover page.

These are all generally the result of over- or under-provision of cathodic protection in the special context of sustained electrical activity.

That is why the correct operation of your sacrificial anode protection system is necessary for the proper upkeep of your boat, irrespective of whether it has a metal, wood or polyester hull; the hasty annual visual inspection, possibly supplemented by its replacement is no guarantee of the effectiveness of the system.

You need to ensure that the current delivered by your anodes is monitored precisely in order to avoid the appearance of unforeseen inconveniences which could prove not only costly but also dangerous.

Furthermore, the speedy identification of potential electrolytic phenomena is essential, especially during long periods of unattended anchorage (winterizing).

Cover photos:
1. Non-osmotic blistering (6 months, a result of cathodic over-protection)
2. Electrolytic corrosion (6 months, a result of cathodic under-protection)
3. Aqueous corrosion (6 months, a result of cathodic under-protection)

A BRIEF OVERVIEW

Metals and liquids (especially water) do not make happy bedfellows. In order to protect the former from the devastating corrosion resulting from the presence of the latter, we implement two complementary techniques at the same time to limit the unavoidable and undesirable consequences of this enforced cohabitation:

- Underwater coatings, made of insulating paint-like materials, themselves covered with antifouling.

- Protective anodes, among which are:

  - **Sacrificial anodes**, which potential is electrically more negative than the potential of the metal to be protected. These are fitted to the majority of leisure craft and are made from alloys of zinc, aluminium and magnesium.

  - **Impressed current anodes** which deliver a controlled DC protective current to ships and large structures and are found only on leisure craft above a certain size.

The corrosion of metals is subject to the potential reduction mechanisms that govern the movement of electrons in an electrolyte (conductive medium); consequently, material is lost and must therefore be the subject of "careful watch".

IF IT ISN'T YOU, THEN IT'S YOUR BROTHER!

A metal in contact with an electrolyte has a natural tendency to lose its electrons and corrode: this is the phenomenon of oxidation causing electrochemical corrosion (or dissolution).

And this is occurs particularly when its protective coatings are destroyed…

But if two metals in contact with each other are immersed in the same electrolyte, this will create an electrical battery and the more reactive of the two (the anode) will lose its electrons in preference to the ones of the less reactive (the cathode). Since these reactions cannot be avoided, it is necessary to ensure that no immersed structural metal (hull, keel, sterndrive, shaft, propeller, thru hull...) or one in electrical contact with another metallic part of the boat (the engine, for example...) can inadvertently become an anode.

Electrons in movement means an electrical current is flowing…

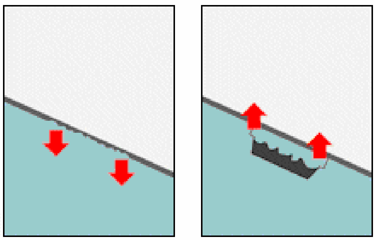
Thus, all metals can be classified according to their natural electrical potential in the galvanic series and it is now relatively easy to predict their behaviour:

For steel immersed in seawater at 20°C this potential is (-) 650 mV and for zinc it is (-) 1000 mV. On this scale, the greater the difference between the metals, the stronger the oxidation will be. Zinc, with a potential much lower. than that of steel will be oxidised in preference to the steel.

What happens when a bronze propeller [potential (-) 280 mV] located at the end of an (active) stainless steel propeller shaft [potential (-) 550 mV], itself controlled by a motor (probably made of steel ...) and fitted to an aluminium hull [potential (-) 650 mV]? The result could be catastrophic if care is not taken! The aluminium hull becomes the anode and therefore will destroy itself irreparably by sacrificing itself more or less rapidly in preference to the other equipment, which is all more cathodic than it is.

Install a protective zinc anode [(-) 1000 mV (as above)] to reverse the situation by repositioning the aluminium as the cathode; the zinc then becomes the anode and then sacrifices itself in preference.

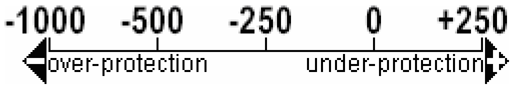
Cathodic protection is the corollary of galvanic corrosion.



The anodes reverse the direction of the electric current and anodic material is lost in preference to the metal being protected...

THE GALVANIC SERIES OF METALS

The galvanic series of metals is nowadays well-understood:



Magnesium anode	**-1600 mV**
Aluminium anode	**-1050 mV**
Zinc anode	**-1030 mV**
Galvanised steel	**-1100 mV**
Alu. sterndrive	**-700 mV**
Aluminium 5000+	**-650 mV**
Mild steel	**-650 mV**
Active stainless*	**-550 mV**
Brass	**-350 mV**
Copper	**-330 mV**
Tin	**-320 mV**
Solder	**-320 mV**
Bronze	**-280 mV**
Lead	**-220 mV**
Nickel	**-150 mV**
Passive stainless*	**-50 mV**

Table A (seawater 10° to 25° C – Ref. Ag/AgCl)
* Stainless steel becomes activated when immersed in sea water!

It enables metals required to coexist in hostile environments to be arranged in order, so as to lower the desired negative electrode potential and obtain effective protection: the more electronegative potential metals deteriorate in preference to the more electropositive ones.

This is essentially empirical knowledge; the multiplicity of alloys greatly complicates the proper understanding of corrosion phenomena.

In short, as you now understand, everything is linked to electrical potentials. And substantial potential at that, since the necessary voltage to provide effective protection from problems is generally between (-) 500 mV and (-) 200 mV below the one of the metal which is to be protected.

Below the lower limit of this range (towards - values), there will be “**over-protection**“ with damage that can be significant for coatings or even for the materials themselves (hydrogen evolution). Furthermore, over-protection may promote the proliferation of limpets (barnacles)…

Above the values shown in Table A (towards + values), there will be "**under-protection**" and therefore more or less severe galvanic corrosion will occur.

GALVANIC VS ELECTROLYTIC CORROSION

- **Galvanic corrosion** occurs when different metals in contact with each other are immersed in an electrolyte. It is a natural phenomenon.

- **Electrolytic corrosion** involves further and far more harmful action by uncontrolled electrical currents produced by an outside source (leakage currents in an electrical circuit, for example...). Though accidental it is very aggressive; it can and must always be avoided.

SACRIFICIAL ANODES

They are called sacrificial because they sacrifice themselves for the benefit of the metals they protect; in return, they need to be regularly replaced.

Theoretically, the size of the current that they deliver over a given period is autoregulated depending upon:

- The material of which they are made (Zn, Al or Mg)
- Their size (dimensions, weight)
- Their purity (particularly, avoid any contamination by steel particles)

Calculations enable their sizes and numbers to be determined for any particular structure immersed in any given electrolyte. However, once again this is essentially empirical knowledge and what works in one case may not necessarily work in another.

ZINC, ALUMINIUM, MAGNESIUM

Sacrificial anodes are usually made of alloys. For convenience, they are usually referred to by their major constituent. From Table A we can see that in seawater, which is more conductive than freshwater, zinc and aluminium are sufficiently effective and are thus preferred. Although they are more sensitive, magnesium anodes wear out more quickly and do not constitute an acceptably economical solution. Their use is reserved predominantly for freshwater.

Furthermore, for an equivalent effect an aluminium anode weighs three times less than a zinc anode and has a more highly electronegative potential…

Finally, an anode is considered to retain its capacity to protect as long as it weighs more than 50% of its original weight.

The theoretical capacity of pure zinc is 820 Ah/kg. Assuming an availability coefficient of 95%, a I kg anode can continuously provide 1 A for 779 h or 0.1 A for 7790 h (equivalent to 46 weeks)...

MOORING CONDITIONS

Mooring conditions have a strong effect on electrical activity, and thus on the consumption of anodes. The properties to be taken into consideration are:

- The speed of the water under the hull (the protection requirements can be multiplied by a factor of 30!)
- Its conductivity
- Its salinity
- Its temperature
- Its pH

A LITTLE (MARITIME…) COMMON SENSE

From the foregoing you can now deduce that the life of your anodes is probably not linked just to your annual careenings, except coincidentally. And their under-consumption does not necessarily indicate a particular problem (contrary to popular belief ...), unlike their over-consumption, which must alert you to seek out reasons[1]…

[1] Any lack of wear is always abnormal

HULL POTENTIAL

Measurement of the hull potential[2] is made using a correctly calibrated control electrode.

Some non-metal boats have interconnections between all underwater metal parts which are connected to a common (ground) protection system. However, for most of the time, these metal parts remain independent and are sometimes protected by their own anodes.

Thus, for a given hull material, the recommended potential measurements should be within ranges:

-1000 -500 -250 0 +250

Wood	**(-) 600 to (-) 550 mV**
Polyester with IB	**(-) 1000 to (-) 750 mV**
Polyester with OB or Z-Drive	**(-) 1050 to (-) 900 mV**
Aluminium	**(-) 1100 to (-) 900 mV**
Steel	**(-) 1050 to (-) 800 mV**

Table B (seawater 10° to 25° C – Ref. Ag/AgCl)

Once again, there will be "under-protection" beyond these limits (towards the positive) and "over-protection" below (towards the negative[3]).

Paying attention to the nature and number of anodes used (including pendent anodes...) and their scheduled replacement whenever necessary will, in most cases, ensure the correct functioning of your boat's cathodic protection.

[2] Or of immersed metallic outfits (wood/polyester hulls)
[3] Look out for negative signs

THE CONSEQUENCES OF OVER-PROTECTION

Over-protection creates conditions for accelerated degradation of protective underwater coatings, as well as wooden hulls and aluminium alloy parts.

Wooden hulls
Wood fibres around protected metal parts are destroyed (alkaline delignification).

Polyester hulls
There are changes to the protective coatings in same conditions (paintwork and/or antifouling).

Steel and aluminium hulls
There is degradation to protective coatings (paints and/or antifouling) and the risk of their detaching through the appearance of even blistering arising from the production of hydrogen at the metal surface; this is particularly the case with aluminium.

Furthermore, over-protection promotes the establishment and proliferation of colonies of limpets (barnacles).

THE CONSEQUENCES OF UNDER-PROTECTION

The most feared and the best known, this consists of corrosion to metal parts, resulting in a loss of material that is sometimes dramatic.

Thus, accidental electrical pollution caused by electrolytic corrosion can sink a ship at anchor in just a few months!

METALLIC EQUIPMENTS POTENTIAL

All metal parts immersed in the same electrical medium should be at the same potential (by interconnection).

If there is no interconnection system [4], they must be individually protected and be within the potential limits shown in Table B.

STRAY CURRENTS

Circulants water-borne circuits are a real calamity for hulls and submerged metal equipment because they generally cause very aggressive electrolytic corrosion[5], able to consume anodes rapidly and irreversibly destroy the affected equipment (corrosion occurs at the points of exit!).

THE 12/24 V DC CIRCUIT

The most common causes are:

- **Leakage currents** in the on-board circuit arise frequently from faulty cables in contact with bilge water. This aspect is particularly sensitive and should be monitored with great care.
- **Breaks in the interconnection system wiring** when this is wrongly used as the ground of the on-board circuit or when it includes more than one

[4] Disputed use
[5] Electrolysis in boating world

connection to this ground, which should never be the case.

- **Cable fault in the ground cable** of the electric propulsion motor. A resistance of 0.01 ohms will cause a voltage drop of 200 mV in a 20 A alternator circuit, by simple application of Ohm's law (V=IR). This voltage drop will become a leakage current flowing along a propeller shaft or Z-Drive[6] with consequences one can only imagine…

It is therefore important, not to say vital, to quickly identify the existence of such leakage currents and, where appropriate, to remedy the problems identified without delay.

Thus, when a leakage current has been detected, the equipment on each circuit should be tested separately:

On-board equipment (non-exhaustive list):

Producers	**Consummers**
Battery charger(s)	Bilge pumps
Main alternator(s)	Freshwater pumps
Genset(s)	Toilet pumps
	Macerator pumps
	Windlass motors
	Navigation lights
	Navigation electronics

[6] On certain sterndrives the anodes are not operational in the raised position

THE 110/220 V AC CIRCUIT

The shore power mains earth connection[7] protects you against electrocution but, on the other hand, passes unwanted leakage currents to every other boat connected, creating a destructive galvanic couple with surrounding equipment (including neighbouring boats ...).

Obviously, wooden or polyester boats are no exceptions in as far as they are usually equipped with propeller(s), shaft(s), sterndrive(s), reverse transmission(s), engine(s), thru hull(s) and, for sailing boats, a keel... all are metal.

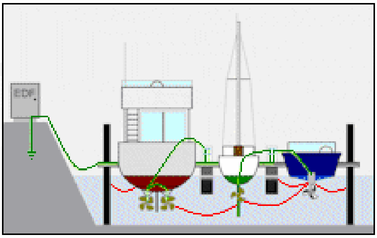
In addition to excessive consumption of anodes this situation is likely to give rise to the various problems mentioned above. This is particularly the case when a difference greater than 10 mV is found between two measurements, with and without shore power.

Similarly, the detection of a difference greater than 100 mV must always be investigated to determine the cause, as the risk of electrolytic corrosion is so real.

There are several technical devices to address the danger: notably, isolating transformers (very safe) and diode insulators.

It is therefore essential, particularly in the case of extended mooring with an AC voltage, to test the electrical insulation of your boat.

[7] Safety regulations require the presence of a ground connection; these are needed for the correct operation of RCDs



Stray currents spread through earth contact threaten your boat when moored and increase corrosion of immersed metals or in contact...

POLYESTER HULLS : WHY CHECK?

Regular checking of immersed outfits electric potential:

1. Informs on anode wear and remaining efficiency without diving or pulling the boat out of water
2. Protects from costly repairs on sterndrive, shaft and/or propeller
3. Identifies possible stray currents from on-board or shore-power circuits

SEA WATER / FRESH WATER

Protection current requirements are greater in sea water but higher driving potentials are necessary in less conductive fresh water (magnesium anodes (-) 1600 mV vs zinc anodes (-) 1030 mV). Always use anodes designed for the wanted purpose. Never install magnesium anodes if you plan going to sea water without specialized advice.

BY WAY OF CONCLUSION

Monitor your anodes regularly – this will prevent many problems by keeping you informed about your boat's electrical integrity and the safety of your moorings.

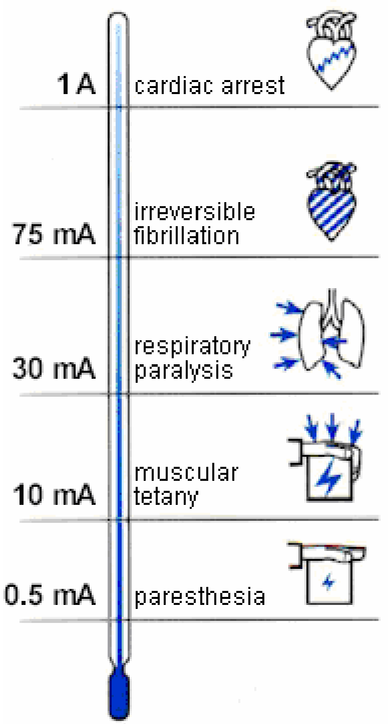
ATTENTION!
Be aware to read the latest version of this document!

Your measurements

Name of the boat	

Measurement's place ▶		#1	#2	#3
Date ▼	Mooring ▼			

The AC circuit is particularly dangerous!



GPS

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