



CORROSION | ELECTROLYSIS

CATHODIC PROTECTION OF SMALL SHIPS

Recreational and working boats < 24m



V10 - REVISED AND EXPANDED

www.galvatest.com



Galvatest plunging sensors allow you to determine sensitivity to corrosion of your boat's hull (steel or alu) or of its metallic immersed equipments and thus lower their associated maintenance costs.

By measuring value of the corrosion potential of immersed metals, **Galvatest** sensors are the simpler, the most efficient, the more reliable and the more economic way to control the efficiency of cathodic protection and detect harmful stray currents originated from aboard or ashore.

A FEW QUESTIONS YOU MAY ASK ABOUT:

- Do I have enough anodes?
- Are they efficient?
- Do I suffer harmful stray currents from board or shore?
- Are my neighbours eating my anodes or my drive (sail or Z-drive)?
- Is my earthing system functional ?
- Does my galvanic isolator or isolation transformer operates properly?
- How is working my impressed current controller?
- Are mooring marina's flotability tanks, piles and steel planks correctly protected?

These are some of the few questions an elementary control of the corrosion electrochemical potential of hulls or metal immersed equipments answers.

Cover picture:

Replacing a corroded element without having correctly diagnosed the cause of the problem exposes you to having to start again in the short term.

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 of corrosion attacks.

These are all generally the results of a lack, if not an excess, 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 protective 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).

40 mA received during a 30 days period will definitively destroy 10 g. of aluminium!

A BRIEF OVERVIEW

In addition to steel, small boats today make extensive use of aluminium, stainless steel and bronze alloys.

But metals and liquids (especially water) do not make happy bedfellows. In order to protect the former from a devastating corrosion while immersed, we implement different complementary techniques at the same time to limit the unavoidable and undesirable consequences of this enforced cohabitation:

- **Oxido-protection**, which is based on the development of the natural protective oxidation layer of the concerned metals,
- **Paint systems**, made of insulating technical coverings, specially developed,
- **Cathodic protection**, including:
 - **Sacrificial anodes**, which deliver a limited quantity of protective current and are fitted to the majority of leisure crafts.
 - **Impressed current anodes (ICCP)** which deliver a controlled DC protective current to boats and large structures and are found only on leisure craft above a certain size.

The corrosion of metals is subject to redox reaction mechanisms that govern the movement of electrons in an electrolyte (conductive liquid medium); consequently, resulting material loss. It is thus a 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 occurring 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 heat exchanger, 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 relatively easy to predict their behaviour:

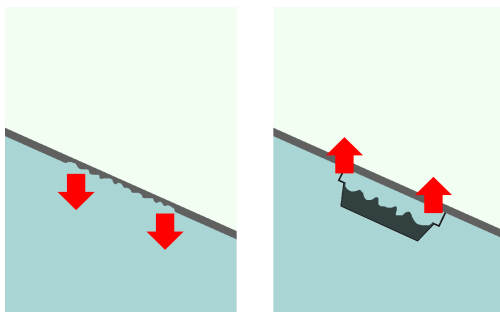
For steel immersed in seawater at 20°C this potential is about (-) 650 mV and for zinc it is (-) 1000 mV. On this scale, the greater the difference between the metals, the stronger the oxidation will be. Zinc, with a potential much

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 an engine (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-known (beware the conventional sign!):

Potentiel de corrosion	Corrosion potential	de/from	à/to
Magnésium et ses alliages	Magnesium and its alloys	-1630	-1600
Anode magnésium	Magnesium anode	-1510	-1460
Anode aluminium	Aluminium anode	-1150	-1050
Anode Zinc	Zinc anode	-1090	-1050
Zinc	Zinc	-1030	-980
Alliages d'aluminium	Aluminium alloys	-1000	-760
Acier doux	Mild steel	-710	-600
Fonte	Cast iron	-710	-600
Acier inoxydable 304, actif	Stainless steel 304, active	-580	-460
Acier inoxydable 316, actif	Stainless steel 316, active	-540	-430
Aluminium bronze	Aluminium bronze	-420	-310
Laiton, tous	Brass, all	-400	-300
Cuivre	Copper	-570	-300
Bronze B62	Bronze B62	-310	-240
Plomb	Lead	-250	-190
Acier inoxydable 304, passif	Stainless steel 304, passive	-100	-50
Acier inoxydable 316, passif	Stainless steel 316, passive	-100	0
Graphite	Graphite	200	300

Eau de mer mouvante 10-27°C Flowing sea water 10-27°C

Table A (values mV for - 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 one.

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 (**blistering**) or even for the materials themselves (weakening hydrogen evolution). Furthermore, over-protection may promote the proliferation of marine organisms (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.



On the backside, cathodic protection promotes encroachment of marine organisms...

GALVANIC AND ELECTROLYTIC CORROSION

Corrosion is a multifaceted and complex phenomenon involving a metal and its environment to return to it's natural state (ore).

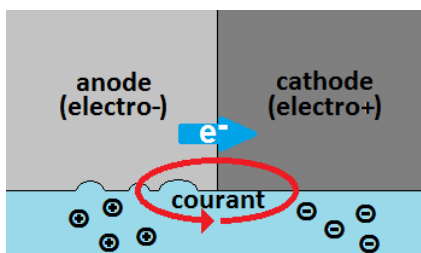
Improperly called “electrolysis” in the world of small boats, it is the result of a transfer of electrons for which three conditions are absolutely necessary:

1. The existence of an anode and a cathode
2. Their junction through a metal link
3. Their immersion in the same electrolyte

So, stopping corrosion involves removing one of these three conditions.

Concerning boats, we distinguish:

- **Galvanic corrosion** occurs when different metals in contact, so in electrical continuity, are immersed in an electrolyte. It is a natural phenomenon with a slow evolution. Corrosion occurs at the contact points, at the metal/electrolyte interface.
- **Electrolytic corrosion**, which mechanism is similar, involves the additional, rapid and much more harmful action of uncontrolled unwanted electrical currents, produced by an external source (leakage from an electrical circuit...). These currents, called leakage currents, will reach the sea (0 V potential) via the path of least resistance. Accidental and very aggressive due to the energy input thus achieved, the latter can and must therefore be constantly detected and avoided.



Remember electrons leave the anode through the metallic link with the cathode (opposite to the conventional direction of electric current). They can't "swim". Charge transfers are made by ions.

AERIAL AND UNDERWATER CORROSION

Although the mechanisms of aerial corrosion are similar to those of underwater corrosion, there is nevertheless a fundamental difference linked to the environment: the presence of an electrolyte – a conductive liquid – is permanent under immersion. This condition alone makes the danger omnipresent and potentially dangerous. It impacts the choice of means of protection and possible corrective measures to be implemented.

Furthermore, while aerial corrosion mainly causes aesthetic damage, particularly to the fitting's welded or crimped parts, underwater corrosion is only visually noticeable when the boat is on land, often once a year and when it is too late.

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 checked and replaced. They must never be painted and it may be necessary to scratch them when put into service, but never with steel...

Theoretically, the size of the protective 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. Resistance between an anode and protected metal must not exceed 1 ohm.

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 20% of its original weight.

The theoretical capacity of pure zinc is 820 Ah/kg. Assuming an availability coefficient of 95%, a 1 kg anode can continuously provide 1 A for 779 h so 0.1 A during 46 weeks...

COMPOSITION

Composition of anodes is essential to ensure a correct behaviour. A tiny impurity can neutralize them: this is why they should never be cleaned with a wire brush.

Anodes are always alloys of their main component and their physico-chemical characteristics are mostly defined by military standards which include US Mil. (USA) and Marine Nationale (France).

Average capacity of anode's alloys:

- | | |
|-------------|-------------|
| • Zinc | 750 Ah/kg |
| • Aluminium | 2 500 Ah/kg |
| • Magnesium | 1 250 Ah/kg |

To prevent potential reverse phenomenons, aluminium anodes are alloyed with Indium, a critical and costly material.

ANODE/CATHODE AREA RATIO

The larger is the cathode surface vs the anode surface, the more unfavourable it is. Cathode painting allows substantial improvement.

INFLUENCING FACTORS

Beside the anodic/cathodic areas ratio, 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 reasons¹...

¹ Any lack of wear is always abnormal

BOAT'S CORROSION POTENTIAL

Measurement of the corrosion potential « E_{corr} » of the boat's hull or of its immersed equipments afloat is made using a correctly plunging calibrated control sensor (reference electrode Ag-AgCl).

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 of underwater metals should be within ranges:

Matériau de coque	Hull material	de/from	à/to
Polyester fibre de verre	Polyester fiberglass	-1100	-550
Bois	Wood	-600	-550
Aluminium	Aluminium	-1100	-950
Acier	Steel	-1100	-850
Embase aluminium	Aluminium drive	-1100	-950
Eau de mer mouvante 10-27°C	Flowing sea water 10-27°C	mV vs	Ag/AgCl

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

There is "under-protection" beyond these limits (towards the positive) and "over-protection" below (towards the negative). 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.

THE CONSEQUENCES OF UNDER-PROTECTION

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

Thus, significative electrical pollution caused by electrolytic corrosion can sink a boat at anchor in just a few weeks!

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. It may also weaken concerned metals.

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

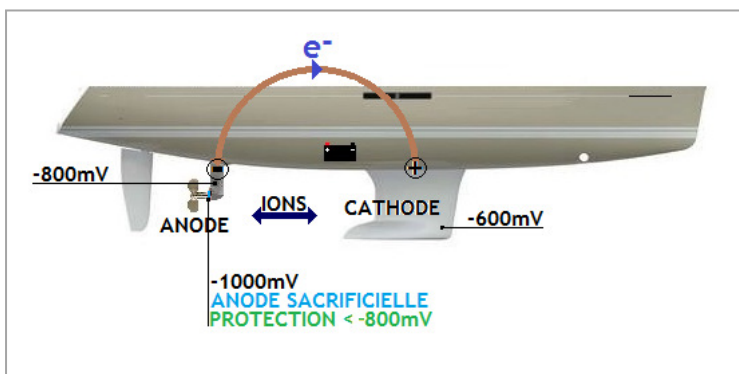
There is degradation to protective coatings (paints and/or antifouling) and the risk of their detaching through the appearance of even blistering arising from the production of hydrogen at the metal surface; this is particularly the case with aluminium.

Furthermore, over-protection promotes the establishment and proliferation of living organisms.

THE CORROSIVE LOOP

The corrosive loop is solely responsible for the corrosion of metal immersed equipments. It can be galvanic originated, electrolytic originated or both galvanic and electrolytic originated.

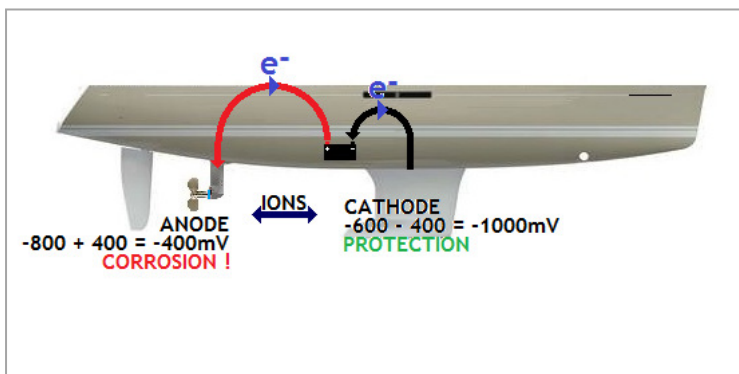
GALVANIC



When a link exists, deliberate or accidental between two different metals (brown circle arc), a natural current travels from cathode to anode and electrons goes the opposite way. Anode is then the metal with the lowest potential. In electrolyte (water), positive or negative ions shut the loop and carry the electric load. Metal from which current leaves loses its electrons, oxydises and corrodes (sail-drive's carter). As electrons always leaves the more electro-negative metal, creating a new link with an even more electro-negative metal is efficient enough to protect it. It is the sacrificial anodes mission and the

primary principle of cathodic protection: sail-drive's carter thus becomes a cathode instead of an anode and is consequently protected.

ELECTROLYTIC

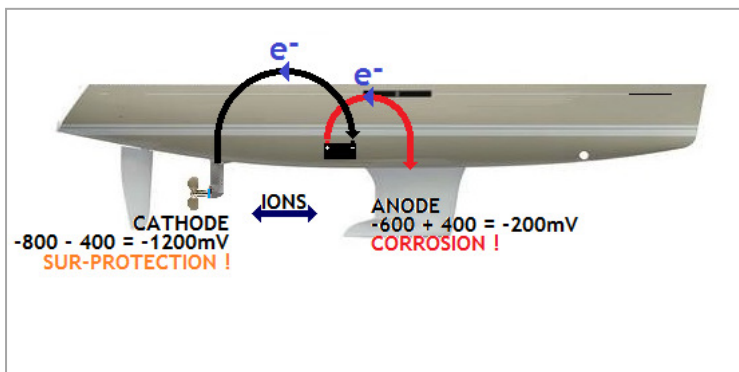


In a similar way, when an external deliberate or accidental current (i.e. leak), is added to the natural galvanic current, metal connected to (+) becomes anode. As it always travels from cathode to anode and electrons the opposite way, it reinforces the corrosive current of the galvanic loop: According to Ohm's law, the more current is present, the greater is the impending danger for the sail-drive. The loss of weight obeys to Faraday's laws². Caution! In an electrolytic loop, polarities are opposite when regarding those of a galvanic loop! Overall logic is maintained.

Thus, an aluminium sail-drive which potential is (-) 800 mV (without sacrificial anode) will « gain » 400 mV

² See calculator on Galvatest web site

(exemple) and then reach (-) 400 mV, much higher than it's corrosion potential. And the higher the potential is, the bigger and the quicker damages will be.



However, there is a situation where an external current, still deliberate or accidental, is not harmful and can even be beneficial. As metal connected to (-) becomes cathode and gains electrons, it's potential then lowers and protect it from corrosion. Galvanic loop is inhibited: it is the main principle of active protection. Quantity of current must however be carefully delivered to avoid over-protection of the metal. Caution! When a metal is too much over-protected, it can loose its paint layers and be fragilized. So reacts aluminium, very sensitive to over-protection.

GENERAL RULE

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

If there is no interconnection system³, they must be individually protected and be within the potential limits shown in Table B.

CORROSIVE STRAY CURRENTS

Making a corrosive loop through water they are a real calamity for hulls and submerged metal equipment because they generally cause very aggressive electrolytic corrosion⁴, able to consume anodes rapidly and irreversibly destroy the affected equipment (corrosion occurs at the points where current exits!).

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

³ Disputed use

⁴ Electrolysis in boating world

- **Cable fault in the ground cable** of the electric propulsion engine. A resistance of 0.01 ohms will cause a voltage drop of 100 mV in a 10 A alternator circuit, by application of Ohm's law ($V=IR$). This voltage drop will become a leakage current flowing along a propeller shaft or S-Z Drive⁵ 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 equipments (non-exhaustive list):

Producers

Battery charger(s)
Main alternator(s)
Genset(s)

Consummers

Bilge pumps
Freshwater pumps
Toilet pumps
Macerator pumps
Windlass motors
Navigation lights
Navigation electronics

⁵ On certain sterndrives the anodes are not operational in the raised position

THE 110/230 V AC CIRCUIT

The implication of alternative currents in terms of corrosion is not clearly demonstrated.

Meanwhile, if the shore power mains earth connection⁶ protects you against electrocution, on the other hand, it allows circulation of unwanted leakage currents to every boat connected, possibly creating destructive galvanic couples 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), exchanger(s), thru hull(s) and, for sailing boats, a keel... all are metal.

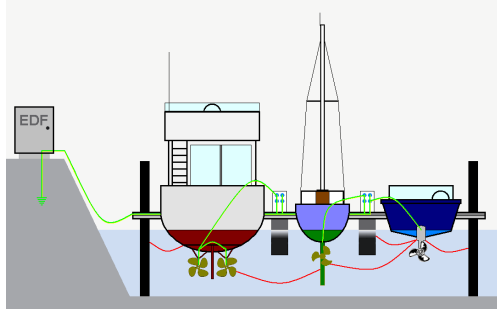
In addition to excessive consumption of anodes this situation is likely to give rise to the various problems mentioned above. This is particularly the case when a difference greater than 10 mV is found between two measurements, with and without shore power.

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.

⁶ Safety regulations require the presence of a ground connection; these are needed for the correct operation of RCDs

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



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

GROUNDING DEFECTS

Ground faults are likely to cause significant failures, particularly on metal hulls. Due to their specificity, they are the subject of a special technical bulletin published by Galvatest.

DIFFERENT SITUATIONS

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 for more than two weeks.

METAL HULL / GRP (POLYESTER)

Protection current needs of steel in coastal sea water is 20 mA/m² wetted surface. It is about 10 times less for aluminium.

While steel corrodes evenly, aluminium has a tendency to pit. Nuance is important because pits concentrates the corrosion and develops in depth. They are then likely to quickly pierce the material.

The loss of material obeys Faraday's laws⁷. Thus, a loss of 10 g observed over a period of 21 days corresponds to a leaking current of:

- 9 A for steel
- 28 A for aluminium

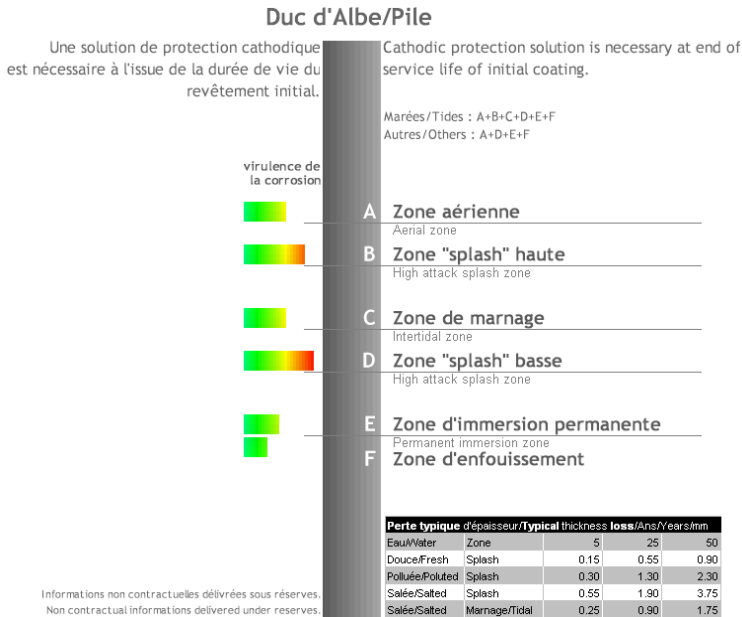
Regular checking of immersed outfits electric potential:

⁷ See calculator on Galvatest web site

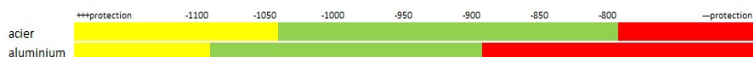
1. Informs on anode wear and remaining efficiency without diving or pulling the boat out of water
2. Identifies possible stray currents from on-board or shore-power circuits
3. Protects from costly repairs on sterndrive, shaft and/or propeller

MARINA'S EQUIPMENTS

Flotability tanks, piles and steel planks are not immune towards corrosion. They are usually designed to last some 20 years. After that period, and despite attentive care, protection issues will probably be necessary. However, due to age of equipment, they will protect it for a shorter period than usual.



BY WAY OF CONCLUSION

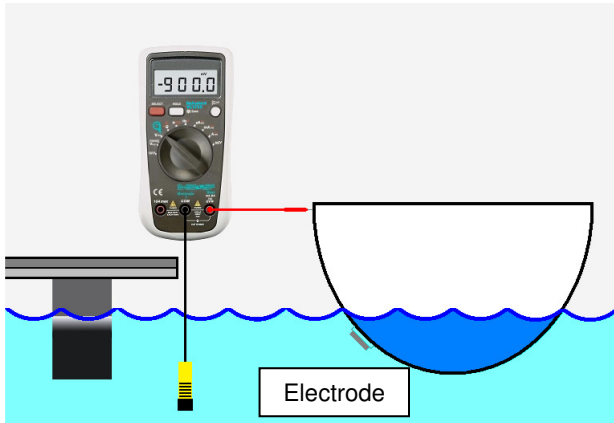


Corrosion is a complex and multifaceted phenomenon. It always occurs at the metal-electrolyte interface. Regularly monitoring the corrosion potential of your hulls or submerged metal equipments using a control electrode will prevent many problems by keeping you informed about your boat's electrical integrity as well as the safety of your mooring. This control tells you about the performance of your anodes and allows detection of harmful in-board or ashore originated stray currents which always go to the sea. It also applies to submerged metallic harbour equipments.

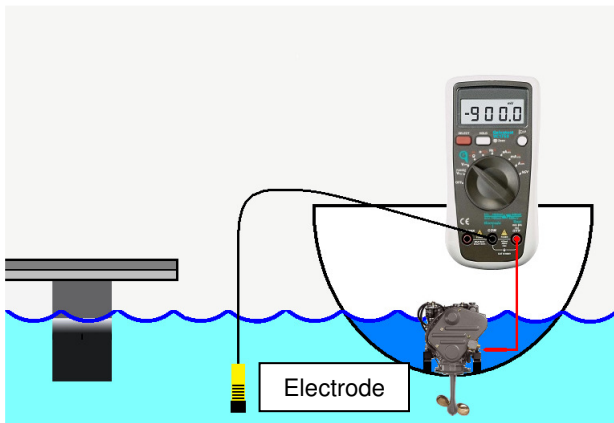
A distinction should always be made between aerial corrosion and submerged corrosion, the latter being distinguished by the permanence of the electrolyte, allowing only the measurement of the corrosion potential of the submerged metallic elements through which are liable to transit, causing the corresponding corrosion, unwanted leakage currents.

Finally, Galvatest publishes many additional technical bulletins concerning boats corrosion on its website.

Measure on metal hull (steel and aluminium)



Measure on immersed equipment (wooden and GRP hull)



ATTENTION!

Be aware to read the latest version of this document!

Your measurements

Name of the boat	
------------------	--

Measurement's place ►		#1 ⁸	#2	#3
Date ▼	Mooring ▼			

⁸ Places #1, 2, 3 must remain the same

Highlights

1. Instant measurement of the corrosion potential of a metal hull or propulsion system tells at once if it is protected by anodes or freely corroding
2. As they always escape to the sea through metals they corrode, harmful stray currents must always be tracked into water
3. A few dozens mV change in corrosion potential while turning on an electric circuit indicates a stray current impairing this circuit
4. Direction and intensity of the observed change allow understanding as well as urgency of the situation



dernière version FR



last edition EN



Please see french edition for eventual complementary information