# Corrosion related electromagnetic signatures measurements and modelling on a 1:40$^{th}$ scaled model

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## Abstract

The Corrosion Related Magnetic Field (CRM) is a part of the static magnetic signature of ships that cannot be precisely quantified for steel hull ships because of the ferromagnetic signature that is added to the CRM in magnetic measurements. For this reason, the CRM is generally evaluated by computation.

Most of CRM models are based on analytical formulas of the magnetic field due to electric dipoles which decrease more slowly with distance than the magnetic signature due to ferromagnetism (spatial decay law in $1/r^2$ instead of $1/r^3$). This is the reason for the following assumption usually met in the technical literature: CRM is dominates the ferromagnetic signature at long distance. But theses models don't take into account a significant part of the CRM source: the currents that flow through the metallic structures of the ship. As a result, conclusion on the distance for which the CRM is dominating the ferromagnetic or the distance for which the CRM remains important can be corrupted.

CRM measurements have been carried out on a ship mock-up to validate a new Finite Element software for CRM that takes into account all the CRM sources: currents in the sea and currents flowing through the metallic structures of the ship. This paper describes the measurements of low levels of CRM on the mock-up, and the first results of its validation with measurements.
*Keywords: cathodic protection; electromagnetic silencing; CRM; UEP; MINE.*

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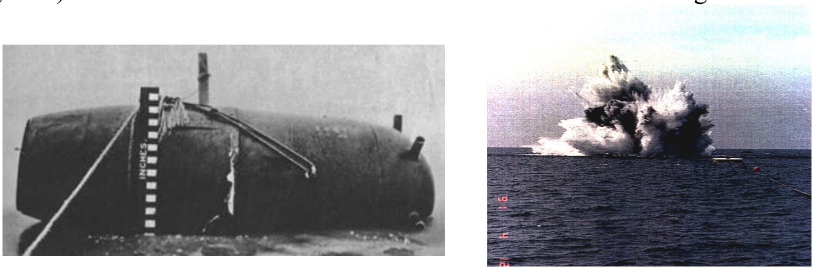
## 1 Introduction

During the Second World War II, intelligent mines have been developed and extensively used. Theses weapons contained several types of sensors, allowing them to detect the proximity of the vessel and wait for the best moment for triggering (see Figure1). They might be equipped either with an acoustic sensor, a pressure sensor and a magnetic sensor or the combination of the three.

A mine explosion at a closed distance of the vessel can cause severe damages to the hull and might sink it rapidly in certain cases.

Some recent conflicts have demonstrated that the mine threat cannot be neglected and is of major concern for all navies because such weapons are very cost effective and their deployments are not risky compared to other weapons.

Another threat can use Electromagnetic indiscretion to detect a target. The MAD (Magnetic Anomaly Detector) is a highly sensitive magnetometer (see figure 2) installed on aircraft and used for submarine detection at high distance.



(a) (b)

Figure 1: (a) A picture of a WWII bottom magnetic mine, (b) an underwater mine explosion.

Figure 2: A maritime patrol aircraft P3-Orion equipped with a MAD.

Usually, a way to represent the risk of a vessel to interrupt its mission is illustrated with equation (1):

$$R \approx 1 - \left[ 1 - \frac{(p \times f)}{L} \right]^n \tag{1}$$

where:

- R: the Risk that the vessel mission could be stopped
- p: the probability of the vessel to be detected
- f: the dangerous front, distance for which the mine explosion will provoke subsequent damages to the vessel
- L: the minefield width
- n: the number of mines

It is possible to have an influence on the risk, *R*. For example, by using a dedicated naval force to hunt or sweep the mine at sea, *n* could be decreased. It is also possible to design the vessel sufficiently strong to resist a mine explosion. If the vessel is designed discreet enough, the probability that the mine sensor can detect the vessel could be limited. Usually, not only one solution is used, but a combination depending on operational and economical parameters.

The role of the DCN Electromagnetic Silencing group is to study and eventually minimise the indiscretion used by mine or aircraft to detect a potential target. Nowadays, mines can be micro-controlled and can exploit all indiscretions generated by a target with high sensitivity. The corrosion related electromagnetic signatures come from different sources but are always dealing with an aspect of galvanic corrosion. The most noted warship galvanic couple is the NAB propeller coupled with the steel hull.

The purpose of this paper is to illustrate how we have proceeded to evaluate, measure and model corrosion related electromagnetic signatures.

## 2 Main challenge

### 2.1 Mechanisms

Usually made from steel, the vessel hull is submitted to corrosion in sea water. The galvanic couple created between the dissimilar metals in electrical contact with the sea water induce some currents in the sea water, which result in the destruction (oxidation) of the less noble metal (called the anode). To fight against such destruction, the solution consists of providing some DC currents (by means of sacrificial anodes or impressed current cathodic protection (ICCP) anodes) in the sea water, on surfaces to be protected. In doing so, the potential of the surface to be protected is brought to a potential referred to as an “immunity potential” where corrosion is minimized.

The solution adopted by DCN for ship corrosion protection is a combination of an efficient coating and a cathodic protection system that protects the ship as the coating degrades over time. Unfortunately, these anti-corrosion currents create an electric and a magnetic indiscretion, which can be used by mines for triggering (see Figure 3).

### 2.2 Difficulties

The main difficulties in studying and modelling the corrosion signatures lie in acquiring accurate experimental data as well as in identifying and implementing a numerical method allowing us to evaluate theses signatures.

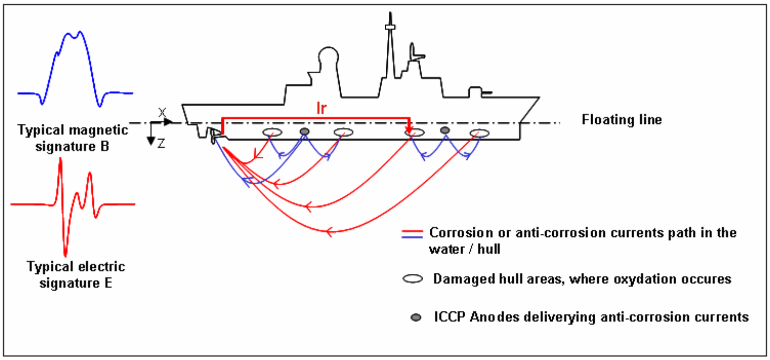



Figure 3: Illustration of the current distribution in a cathodic protection problem.

In order to have the best control as possible on all parameters involved in the corrosion and signatures problems, it has been decided to use a physical scaled model.

Measurements took place at the U.S. Naval Research Laboratory, Center for Corrosion Science and Engineering, Marine Corrosion Facility in Key West, Florida. This laboratory, focused on corrosion studies, incorporates and electrically isolated, 208 cubic meters test tank, instrumented for corrosion and electric field measurements.

Electric signature measurements require low noise sensors and a high quality electronics amplifier. The natural ambient electrical noise is quite low. As a result, it is possible to obtain excellent measurements. For the magnetic signature measurements, the problem is complex because several parameters are to be taken into account in order to obtain exploitable measurements.

- The ambient geomagnetic field is high, several thousand times more than that of the target magnetic field strengths to be measured.
- The ambient lab magnetic field is perturbed (metallic structure, periodic passage of trucks, etc.).
- Presence of ferromagnetic sheets (damage area) on the model.
- The CRM signature is very low due to the scale effect (40 times less than expected for full scaled vessel)

For all of these reasons, direct CRM measurements were not possible. It was therefore decided to acquire differential magnetic measurements with all the contributors with and without the ICCP system ON. In doing so, the magnetic contribution of the ICCP system was extracted from measurements analyzing the field difference. The validity of these differential measurements were considered satisfactory because it was possible to set the ICCP system in the same configuration and status during all the acquisition of measurements by maintaining control on the current density and potential along the model.

# 3 Physical scale modelling

## 3.1 1:40th scaled model

A 1:40th scale frigate model was built and equipped with an equivalently scaled ICCP system, discreetly wired damage areas, representing surface coating damage areas, and numerous hull Silver- Silver Chloride (Ag/AgCl) reference cells utilized in the monitoring of the surface hull potential fields and for ICCP system control (see Figure 4).

The discreet damage areas were wired such that each individual steel or NAB electrode could be switched in or out of circuit to enable several different damage scenarios. More importantly, the ability to electrically isolate each electrode was imperative as to not impede the overall CRM measurements by introducing small galvanic currents that would be present if any two electrodes were wired to one switch and switched out of circuit as a pair.

The entire electrical circuit and wire pathways of discreet model components were implemented on the model with accuracy and followed two different, isolated separate circuits (see Figure 5). Both circuits were designed that they could be then switched on or off in order to evaluate the importance of the structure current return path on the magnetic signature comportment.

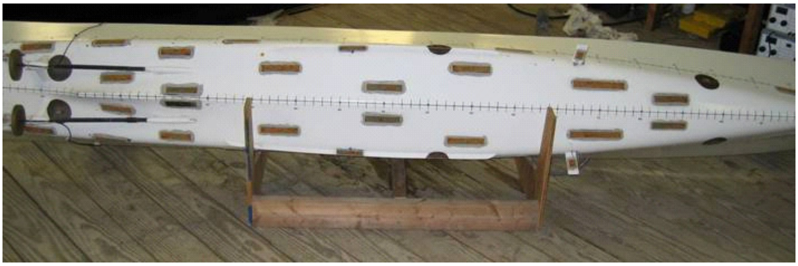


Figure 4: 1/40th scale model mock-up with hull coating damage areas.

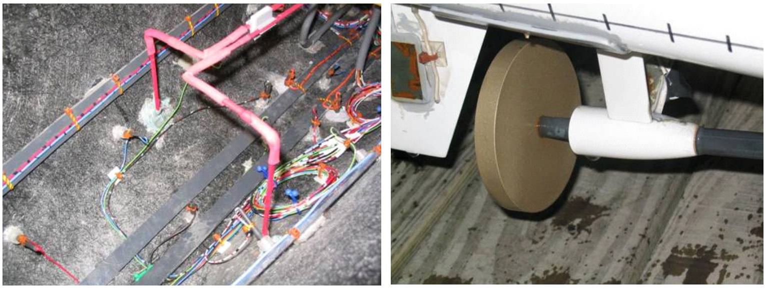


Figure 5: Pictures of the detailed wiring of anode cables (right) and NiAl Bronze Prop disk (left).

### 3.2 Measurements

Measurements have been separated into two different parts, each one with its own technique:

- The Electric signature (UEP) measurement. For this signature, a 2-axis electric sensor (Silver/silver chloride electrode) has been used. Acquisition has been made by moving the sensor under the model and scanning electric signature during the displacement.
- The Magnetic signature (CRM) measurement. Three 3-axis magnetometers (Bartington® MAG03MSS-L70 MSS) have been installed on a rigid non magnetic mast. In the case of magnetic measurement, it is highly difficult to move the magnetic sensor in a very important magnetic ambience. As a result, acquisition has been realised with sensors stopped. Sensors displacement was then realised before new measurement.

The configuration of the measurement is illustrated in Figure 6. Measurements were taken on three longitudinal lines, at different three different distances from the model.

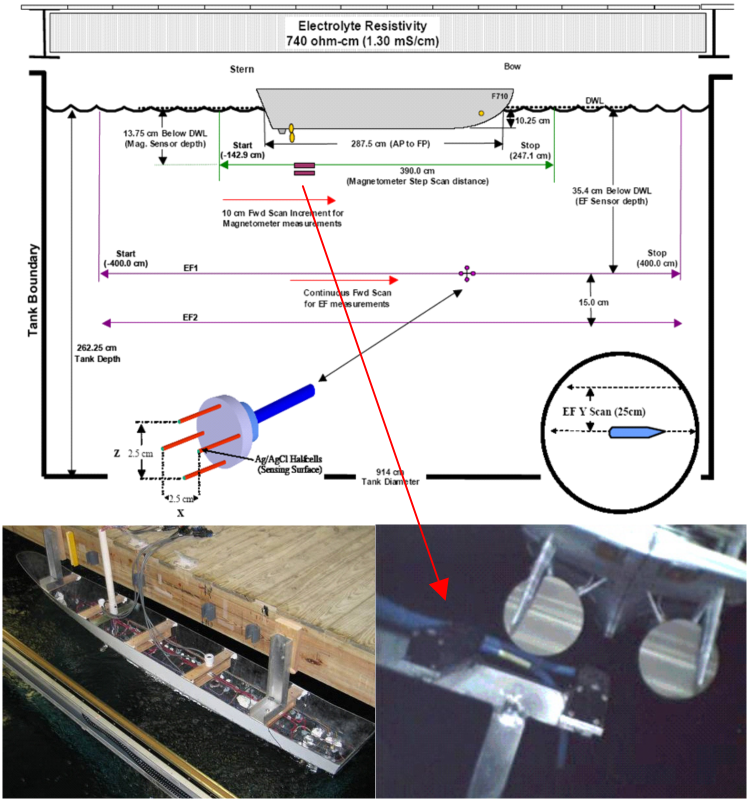



Figure 6: Schematic and pictures of testing tank setup, mock-up in test and close-up of magnetometers under stern.

### 3.3 Modelling

The main target of this study was to measure the corrosion related signatures in order to have at our disposal a set of experimental data but also to identify and validate the tools by which to evaluate theses signatures on any different operational scenario.

The 1:40$^{th}$ scale model has been modelled using finite element software (see section 6). Additionally, both of the complete electrical circuit pathways, inside the model, have been described and meshed, in order to evaluate their impact on the signature (see Figures 7 and 8).

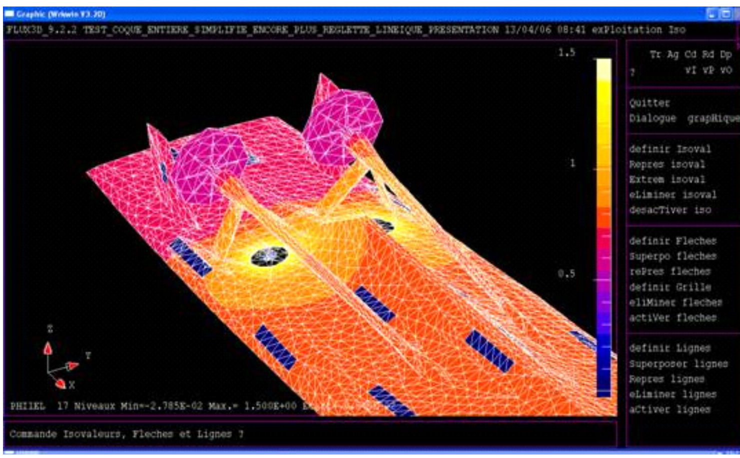



Figure 7: Aft part of the f.e.m scale model with anode and damage areas.

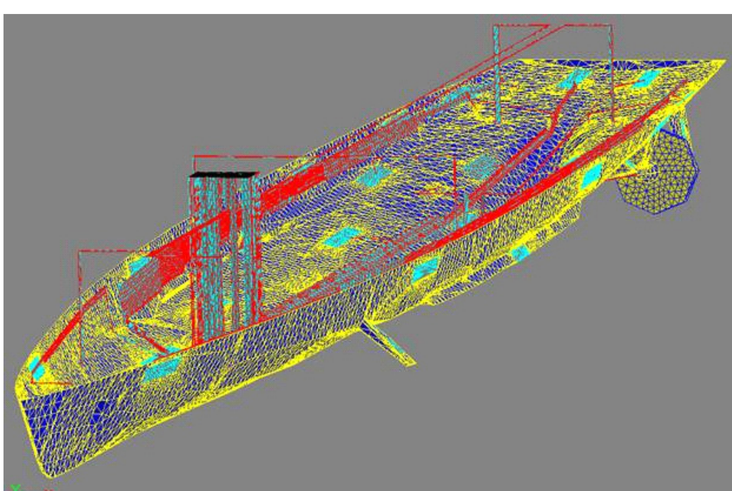


Figure 8: Internal electrical pathways description and meshing.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# 4 Comparison

## 4.1 Electric signatures

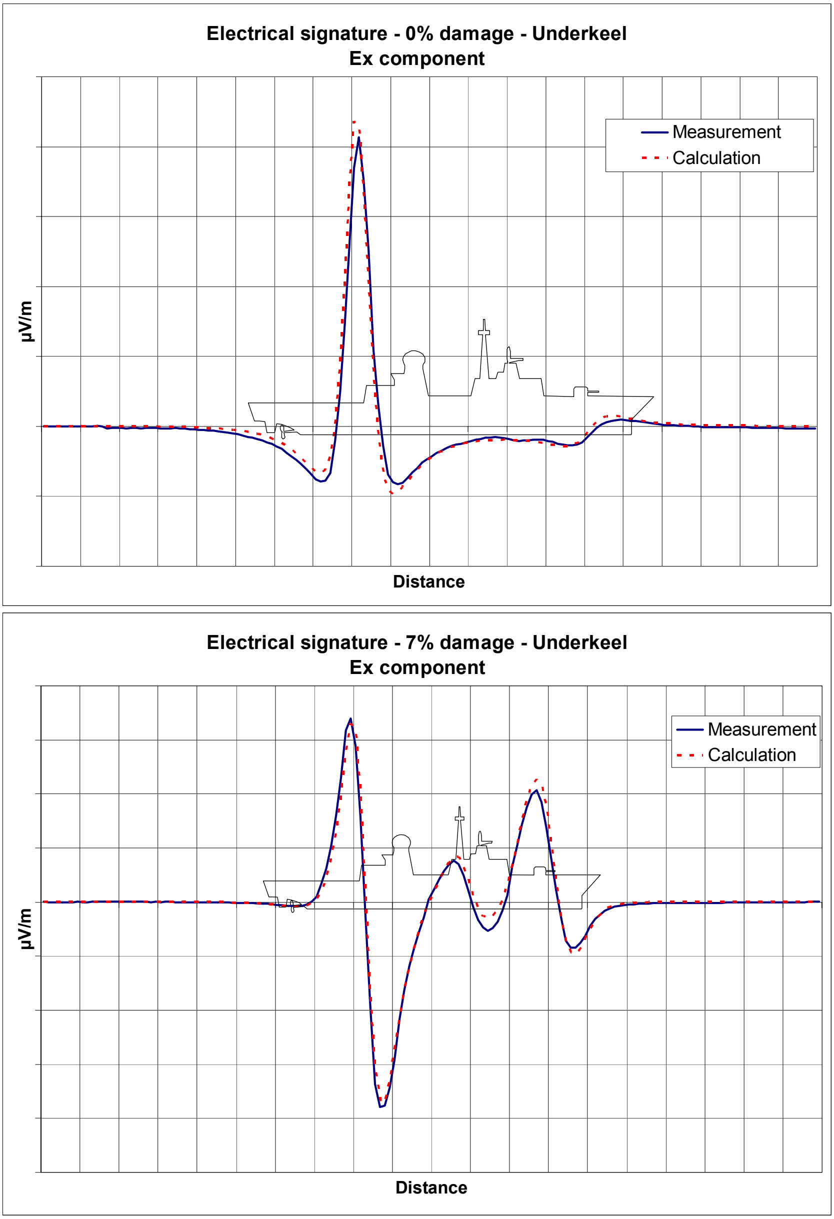


Figure 9: Comparison between UEP calculation and measurement for two different damage scenarios (0% and 7%).

## 4.2 Magnetic signatures

The CRM measurements shows clearly that the way the DC current is flowing back through the structure (large loop electrical path or small loop electrical path) has a major role in the CRM magnitude (see Figure 10) and certainly on its spatial comportment (decay law in $1/d^2$ or $1/d^3$ or an intermediate) according to the measurement distance.

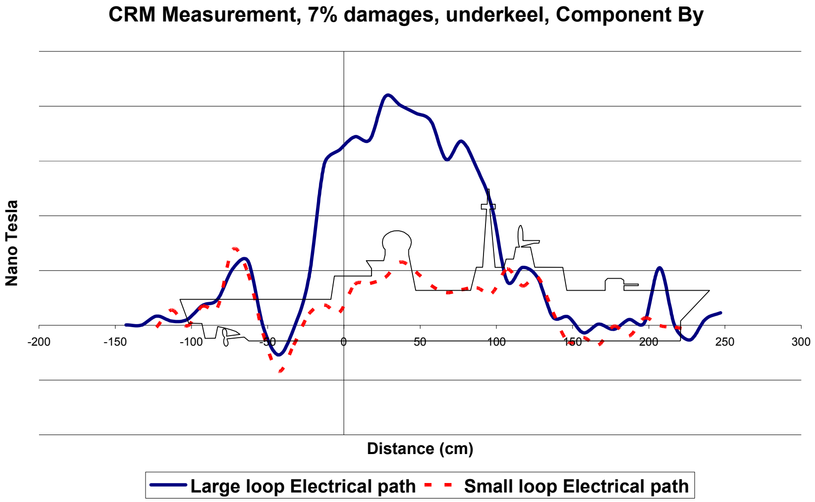


Figure 10: CRM measurement for 2 electrical different wires.

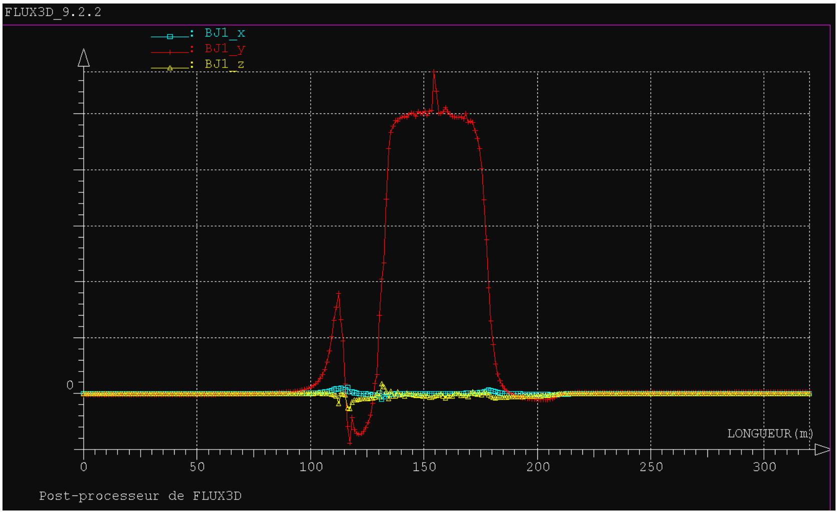


Figure 11: Preliminary CRM computation result.

The validation of CRM computation is not yet completed (see Figure 11). The first preliminary modelling result shows that calculations seem to be coherent with the measurement. The study is still in progress.

## 5 Conclusions and further studies

Calculations of the electric signatures have shown excellent correlations with measurements. Calculations of the CRM signatures of the 1:40$^{th}$ scaled model are still in progress. Preliminary results have shown interesting results but deeper investigations shall be undertaken. Once the calculations are validated, it is intended to study different operational configurations:

- Influence of a ferromagnetic hull on the CRM signature comportment
- Identification of the CRM decay law related to the electrical configuration
- Study of the CRM signature on non magnetic hull vessel (GRP, Titanium, stainless steel, carbon, etc.)

Then, it should be possible to determine the importance of the CRM signature related to the other magnetic sources and define in which conditions and distance, the CRM signature becomes dominant.

## 6 Finite element software

Calculations were done with Flux® software. The Electrolysis module allows handling cathodic protection problems for complex structures, such as warship and calculating the related electromagnetic signatures (UEP and CRM). Its unique feature is to take into account the whole current distribution (in the water and also in the metallic ship structure). Equations (2, 3) solved by Flux® are:

$$div\left([\sigma]\,\vec{grad}(V)\right) = 0\,. \qquad (2)$$

in the water and the metallic structure.

Solving this equation using the finite element method gives distributions of the electric potential V, of the electric field *E* (*E*=-*gradV*) and the current density vector *j* (*j*=-$\sigma$ *gradV*). Then, Flux® computes the magnetic field *H* using Biot and Savart law:

$$\vec{H}(\vec{r}) = \frac{1}{4\pi}\iiint \vec{j}.d\upsilon \wedge \frac{\vec{r}}{r^3}\,. \qquad (3)$$

in the metallic structure and in the water.


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