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## INVERSION IMPROVEMENT OF A CORROSION DIAGNOSIS THANKS TO AN INEQUALITY CONSTRAINT

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**Abstract.** This article presents a direct application of a Tikhonov inversion with a quadratic constraint applied in the case of a corrosion diagnosis. The main originality of this method is to inject physical information during the inversion to automatically restrict the Tikhonov parameter space. This application is then tested on a real case of corrosion diagnosis from electrical measurements in the water.

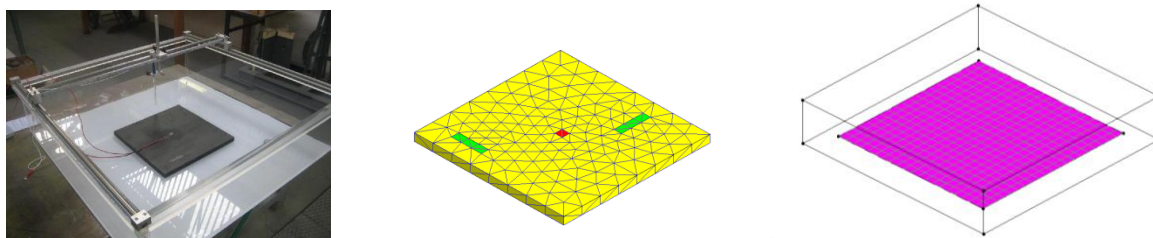
**Keywords:** Corrosion diagnosis, Electromagnetism, Inequality constraint, Tikhonov method

### INTRODUCTION

An underwater steel structure needs to be protected from corrosion; it is the cathodic protection principle. This system implies the circulation of currents in the water and so an electromagnetic field. This field can be measured and then used to make a corrosion diagnosis of the structure. Such a diagnosis tool needs to model the physical behavior of the structure and build a numerical system which will then be inverted. This system is unfortunately often ill posed and different inversion techniques have been tested. Finally, the Tikhonov one has been kept and provides good results in simulations. Such results have been presented in another article [1] and we propose to give a main improvement by constraining the Tikhonov parameter choice thanks to an inequality imposed to the structure. After having described the case tested, the method and its results will be described.

### CASE TESTED AND PRELIMINARY RESULTS

The structure used is a simple parallelepipedic piece of steel covered with an isolated painting unless two parts which simulate the corrosion defects. It is equipped with an adapted Impressed Current Cathodic Protection and a monitoring of the anodic current injected. Some electric potential measurements are made in the water that fulfills the testing bowl.



**Figure 1.** Empty measurement bowl (on left), isolated mock-up tested with a red anode and 2 green defects (on the middle) and measurements localizations (on right)

Two unknowns are set on the whole surface of the structure: the electric potential and the current density. Only the current density delivered by the anode is known. After having meshed the structure, an interaction matrix between each unknown of all meshing elements is built from the third Green Identity, called *forward matrix*. In a second time, another interaction matrix is built representing the interactions between all unknowns and the measurements localizations. This last system is called *inverse matrix* as it links all sources to the measurements. It can be restricted to a new one with fewer unknowns by using the forward system which simplifies one kind of unknown. In our example, the only value known value is a current density, so we obviously chose to keep current densities as unknowns. Finally we obtain a system under the form of:

$$(1) \quad \mathbf{A.X} = \mathbf{B}$$

In this equation, X is the unknown vector containing the current densities on the boundaries which can be found with the Tikhonov method, leading to minimizing the following quantity:

$$(2) \quad \|\mathbf{A.X} - \mathbf{B}\|^2 + \lambda^2 \|\mathbf{L.X}\|^2$$

$\lambda$  is the Tikhonov parameter to find from the choice of the regularization matrix  $\mathbf{L}$  which will be the identity one here (order 0). The results obtained manually are the following:

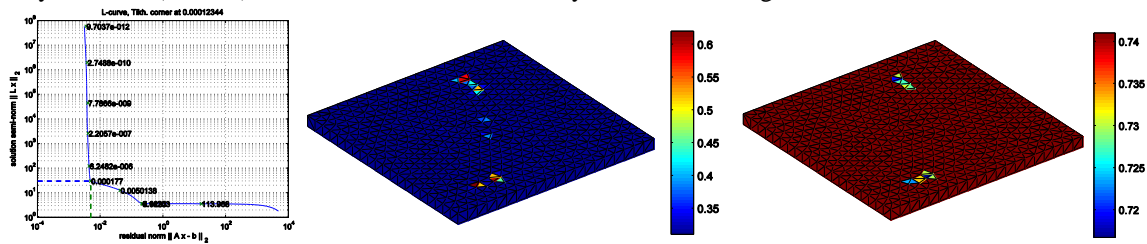


Figure 2. L-Curve obtained (on left), current density results in A/m<sup>2</sup> (on the middle) and potential results in V (on right)

Negative current densities and lowest potential areas correspond to corroded areas. The ones obtained with the choice of  $\lambda$  equal to  $1.2 \cdot 10^{-4}$  match the paint defects, but this choice has to be done manually.

### CONSTRAINING WITH AN INEQUALITY

The principle of this method is to limit one norm of equation (2) from the knowledge of a physical behavior and minimizes the other [2]:

$$(3) \quad \text{Minimize } \|A \cdot x - B\| \text{ with } \|L \cdot x\| \leq \alpha \quad \text{or} \quad \text{minimize } \|L \cdot x\| \text{ with } \|A \cdot x - B\| \leq \beta$$

In our case, the only information we have are the quantity of current injected (and his conservation in the domain) and the measurement error (10% of the differential extreme values). Here we see the interest of taking an order zero regularization: in this case  $\|L \cdot X\|$  is the sum of currents densities on the structure (except on the anode). As all meshing elements have the same surface, it is simple to major the  $\|L \cdot X\|$  quantity (find  $\alpha$ ) by the sum of anodic current densities.

To assure a good  $\alpha$  value, we have to introduce the effect of the measurement error. As we have an estimation of it, its impact has to be found on system (1), where  $\mathbf{B}$  is not the measurement vector but its image built during the simplification of the *inverse system*. From a numerical analysis of this transformation effects, we can see that this 10% of measurement error can imply a 50% difference on the residual norm  $\|A \cdot X - B\|$ . During the minimization of (2), the regularization norm  $\|L \cdot X\|$  would get the same error.

The last question remaining is the meaning of this information: does  $\alpha$  need to be increased or reduced? Increasing the space of  $\lambda$  research, by increasing  $\alpha$ , leads to less regularized solutions which are noisier and more difficult to read. The preference is given to most regularized solutions, by drastically decreasing  $\alpha$  by 50%, its lowest value. In the case presented in the last section, the solution automatically obtained corresponds to  $\lambda$  equal to  $1.87 \cdot 10^{-5}$  and is pictured below:

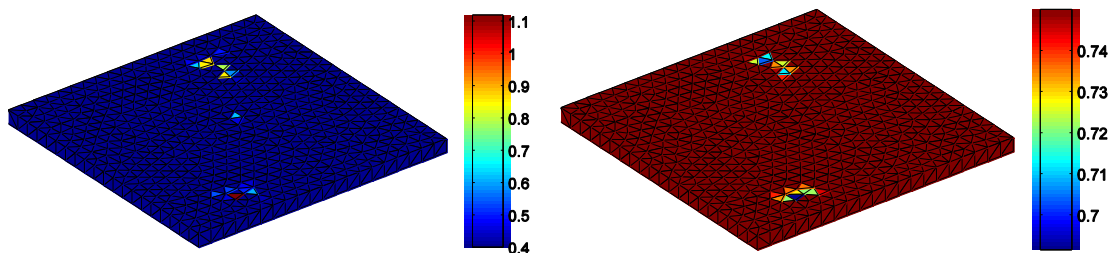


Figure 3. Current density results in A/m<sup>2</sup> (on left) and potential results in V (on right) obtain with the constraint

The results obtained with this method and real measurements are quite good: with only physical information and an estimation of the measurement error, the diagnosis tool provides the good corroded areas.

### CONCLUSIONS

The constraining of the parameter searching space during a corrosion diagnosis is a powerful tool to automatically find an acceptable solution. This imposes to know a little information about the measurements and the system. These new data could be used with other methods such like the Global Cross Validation but with less viewable results.

### REFERENCES

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