



HAL
open science

Shell's magnetization identification from very close magnetic measurements

Yannick Vuillermet, Olivier Chadebec, Jean-Louis Coulomb, Laurent Demilier, Laure-Line Rouve, Gilles Cauffet

► **To cite this version:**

Yannick Vuillermet, Olivier Chadebec, Jean-Louis Coulomb, Laurent Demilier, Laure-Line Rouve, et al.. Shell's magnetization identification from very close magnetic measurements. COMPUMAG 2009-17th Conference on the Computation of Electromagnetic Fields, Nov 2009, Florianopolis, Brazil. pp 15-16. hal-00441234

HAL Id: hal-00441234

<https://hal.science/hal-00441234>

Submitted on 10 Nov 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Shell's magnetization identification from very close magnetic measurements

Y. Vuillermet^{1,2}, O. Chadebec¹, J.L. Coulomb¹, L. Demilier², L.L. Rouve¹, G. Cauffet¹

¹Grenoble Electrical Engineering Lab (CNRS, Grenoble INP, UJF), Université de Grenoble
ENSE3, BP 46, 38402 Grenoble, France

²DCNS, 2 rue Sextius Michel, 75732 Paris cedex 15, France

Abstract — This paper presents an algorithm dedicated to the determination of shells unknowns magnetization. Thanks to magnetic measurements realized on sensors located very close to ferromagnetic material, an inverse problem is solved enabling the determination of the whole magnetic state of the device. The method is experimentally validated on a mock-up of submarine, the purpose of the study being the prediction of its magnetic anomaly from onboard measurements.

I. INTRODUCTION

Most part of submarines are made of steel. One of the drawbacks using such material is that steel is ferromagnetic. The hull of the submarine, placed in the earth's magnetic field and subjected to important pressure effect, get a static magnetization. This phenomenon is well-known and called magnetostriction. This magnetization creates a local static magnetic anomaly around the submarine and can lead to its detection or localization by magnetic sensors embedded in airplanes or even worse in mines. Therefore, for decades, worldwide marines are looking for reducing this magnetic anomaly by setting up large coils in the whole ships feeding them with adapted currents. Before achieving the reduction of anomaly, it is necessary for the ship to evaluate its own magnetic anomaly. The key point of such system is the identification of the magnetization of the ship's hull and this problem is quite difficult to solve. Indeed, the magnetization can be divided in two parts: an induced one, due to the reversible reaction of the material in the inductor field, and a remanent one due to the magnetic history of the material (which depends on hysteresis, mechanical and thermal constraints). The computation of the induced magnetization is now a well-known problem, however, the remanent part is impossible to evaluate with a deterministic calculation because we have no access to the magnetic past of the material. Moreover, even if we had such knowledge, existing models would be too complex to be applied to 3D geometries. It is then necessary to use magnetic measurements to determine the total magnetization of the hull. Thus, the main goal is to solve an inverse problem (i.e. determination of the sources by knowing the effects) with magnetic sensors placed in the air region closed to the hull.

This problem has already been studied and the magnetization identification has already been achieved when sensors could be located far enough from the sheets and with a simplified mock-up of a surface ship [1], [2]. Some of main results of this problem will be reminded in this paper. However, this method has not been tested yet on realistic

mock-up of a double-hull submarine with an important magnetic sensors number placed between the two hulls.

II. BACKGROUND THEORY

A. Forward modeling

Let us consider a device composed of a ferromagnetic sheet S with a thickness e and placed in an inductor magnetic field \mathbf{H}_0 (the earth's magnetic field, for instance). This sheet has an unknown static magnetization \mathbf{M} which contributes to the global magnetic field. Therefore, field \mathbf{H} is the sum of the inductor field and the field created by the shell itself. The field generated by the ferromagnetic material is directly linked to its magnetization by a classical volume integral equation. For a sheet configuration, it is standard to assume that the magnetization is tangential to the shell and constant through it, its permeability being high and its thickness e being low in comparison with other dimensions. Therefore, the integral equation can be written as follows:

$$\mathbf{H} = \mathbf{H}_0 + \frac{e}{4\pi} \nabla \int_S \frac{\mathbf{M} \cdot \mathbf{r}}{r^3} dS \quad (1)$$

where \mathbf{r} is the vector between the point where \mathbf{H} is expressed and the integration point on the S surface of the shell. For complicated geometries, this equation has of course no analytical solution, it is then necessary to discretized it to get a numerical expression. Lets us consider that surface S is meshed into n surface patches with a uniform magnetization \mathbf{M}_i associated to each of them. Equation (1) becomes:

$$\mathbf{H} = \mathbf{H}_0 + \frac{e}{4\pi} \sum_{i=0}^n \nabla \int_S \frac{\mathbf{M}_i \cdot \mathbf{r}}{r^3} dS_i \quad (2)$$

This equation is a vector one and depends linearly from the \mathbf{M}_i values. Let us remember that the magnetization is tangential to the surface S . Each patches magnetization has then two degrees of freedom. Therefore, equation (3) can be represents as a system of equations:

$$[\mathbf{H}] = [\mathbf{H}_0] + [\mathbf{A}][\mathbf{M}] \quad (3)$$

where \mathbf{H}_0 and \mathbf{H} are vectors of 3 components (each component of the inductor and total field), \mathbf{A} is a $3 \times 2n$ matrix which represents the interaction linking the sources to the field and \mathbf{M} is the $2n$ magnetization vector (2 components per meshed element).

B. Inverse modeling

Let us now imagine that we want to determine \mathbf{M} vector (an image of the magnetization of the sheet projected on it

mesh). A solution is to place magnetic sensors around the shell to have a measurement of \mathbf{H} at a given point of the air region. Let us consider that m tri-axis magnetic sensors are placed around the shell, (3) leads to a Matrix system where \mathbf{H} is measured, \mathbf{H}_0 is known (the position of the device in the earth's magnetic field is known), \mathbf{A} is a $3m \times 2n$ matrix (the coefficient of the matrix can be computed with numerical integration techniques) and \mathbf{M} is searched. To get \mathbf{M} , it remains to solve this system. Unfortunately, this task is not so simple and several aspects can lead to very uneasy resolution process:

-*The system is underdetermined:* If the shell geometry is complicated and the magnetization has important local variations, a very fine mesh is needed to accurately represent the real device. The sensors number being limited, we are faced to a linear system with fewer equations than unknowns.

-*The system has a poor condition number:* This mathematical property leads to an unstable solution. In fact, the measurement vector is associated with a non negligible range of noise and a poor condition number will amplify it during the resolution process to give a divergent solution.

This Inverse problem is said ill-posed. In order to solved it, [1] proposes to add others equations representative of the magnetic behavior of the shell. In our case, it enables to write $2n$ additional equations and to add them to the previous system. The dimension of the research space is therefore considerably reduced and a standard single value decomposition, which returns the solution with the minimal norm generally, succeeds. Let us notice that this approach is efficient if sensors are located sufficiently far enough to ensure a global magnetic observation of the whole device. However, in a real naval application, magnetic sensors have to be placed very close to the hull to get a sufficient signal level and to avoid magnetic disturbance. In this configuration, the solution proposed by [1] failed, returning a non satisfying solution. It is then necessary to use additional a-priori information to select the good solution. It is done by combining the classical approach to a regularization method like proposed in [3]. This kind of method ensures the stability of the solution and improved magnetization identification process.

III. EXPERIMENTAL VALIDATION

A submarine double-hull mock-up of about 3.5 meters long has been designed, built and placed on a railway in a field simulator. It has been instrumented with 75 bi-axis fluxgate sensors and 5 tri-axis ones placed very close to the hull. Above the mock-up, another fluxgate sensor has been placed. By moving the submarine over it, we get a measurement of the anomaly to compare it with the predicted one. Then, the accuracy of the inversion process can be evaluated (Fig.1.). Pictures of the experimental set-up are shown on figure 2. The mock-up has been placed in a realistic magnetic state with a strong permanent magnetization.

The whole geometry of the mock-up is meshed into more than 4000 surface elements. So, about 8000 unknowns, fully describing the magnetization, have to be determined. From

sensors; 165 measurement equations are get, the system is then strongly over-determined. To reduce the size of the research space, 4000 equations, representative of the intrinsic magnetic material behavior are added. Then, the matrix system is regularized to finally get a magnetization distribution which seems to be satisfying (Fig.3.). From this magnetization distribution, it is possible, by applying a matrix relation similar to (3) to compute a predicted field on a reference line located outboard the submarine. As it is shown on figure 4, the predicted and the measured field present a very good adequacy.

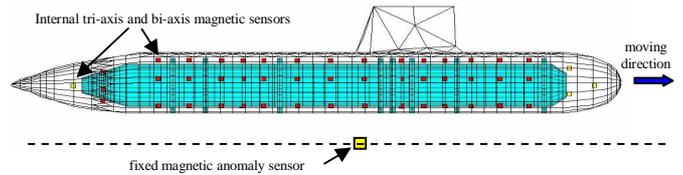


Fig 1: Mock of a double hulls submarine with the mesh, internal fluxgates sensors (bi-axis in red and tri-axis in yellow) and anomaly measurement line.



Fig 2: Pictures of the experimental set-up Experimental results

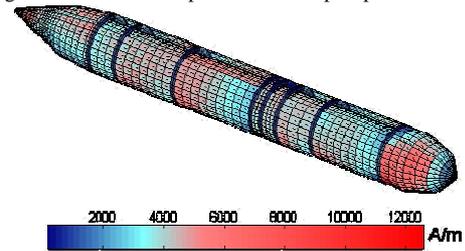


Fig 3: Reconstructed hull's magnetization

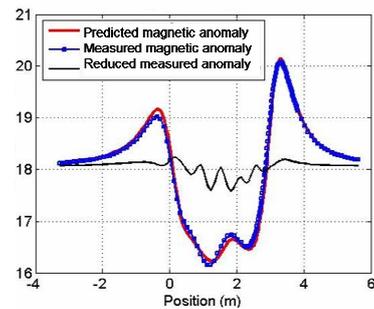


Fig 4: Results of the experimental set-up (measured, predicted and reduced magnetic fields)

IV. REFERENCES

- [1] O. Chadebec, J.L. Coulomb, J.P. Bongiraud, G. Cauffet, P. Le Thiec, "Recent improvements for solving inverse magnetostatic problem applied to thin hulls", IEEE Trans. Magn., vol.38, pp.1005-1008, 2002.
- [2] Yang, C.-S., Lee, K.J., Jung, G., Chung, H.-J., Park, J.-S., Kim, D.-H., "Efficient methodology for solving an inverse magnetostatic problem by utilizing material sensitivity", Journal of Applied Physics, Volume 103, Issue 7, 2008
- [3] A. N. Tikhonov, V. Y. Arsenine, "Solution of ill-posed problem," Wiston/Wiley, Washington , 1977.