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# A priori Bayesian Information for Inverse Resolution of Integral Formulation applied to Thin Regions Magnetization Identification

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**Abstract**— An algorithm for the reconstruction of the magnetization inside an iron sheet is proposed. The magnetization distribution is reconstructed from magnetic measurements made on sensors placed in the surrounding air region. The problem consists in identifying magnetic charges thanks to Bayesian a priori information. The charges derive from the divergence of the flux density through element facets. The efficiency of the method is demonstrated with a numerical application.

**Index Terms**— Bayesian inference, magnetization identification, magnetostatic inverse problem, volume integral method, thin magnetic region.

## I. INTRODUCTION

A magnetic ferromagnetic sheet has two kinds of magnetization. The induced one is the reversible magnetic reaction of the material to an inductor field and can easily be computed. The case of the permanent one, which depends on the magnetic history of the sheet, is more problematic. Its determination needs the use of magnetic measurement in the surrounding air region and the solving of an inverse problem. In this paper, we focus on a new approach for the inversion of a recent integral formulation dedicated to the sheet geometry [1], which fills gaps of poor conditioned system and is lighter and more accurate than the method presented a few years ago [2]. It can be applied to the evaluation of magnetic anomaly created by navy ships or submarines in order to reduce the risk of detection or destruction by magnetic mines.

## II. MAGNETOSTATIC FORWARD PROBLEM

Let us consider a ferromagnetic thin magnetic region  $\Omega$  with a relative linear reluctivity  $\nu$ , a given remanent magnetic state and placed in an inductor magnetic field  $\mathbf{H}_0$ . The approximation of thin element simplifies a volume problem to a surface one by considering that the magnetic induction in the active region is uniform according to the thickness and is tangential to the sheet. In [1], an integral formulation considering the flux of induction  $\mathbf{B}$  flowing in the shell as unknowns has been proposed. This formulation is interpolated by Whitney 2-form shape functions and in order to ensure the free-divergence of the flux, the resolution is performed in the basis of independent fluxes  $\Phi_{BI}$ . Applying the surface divergence operator to  $\mathbf{B}$ , we get an equivalent charge distribution  $Q$  which can be used to compute the field  $\mathbf{B}_{mes}$  created by the shell in the air region [2]. This charge distribution can be physically interpreted as the flux flowing from the shell to the air. The relation linking this charge distribution can be writing in a matrix format:

$$\mathbf{B}_{mes} = \mathbf{A} \mathbf{Q} \quad (1)$$

## III. INVERSE PROBLEM FORMULATION

At this step, our aim is to solve the inverse problem meaning to determine  $\mathbf{Q}$  vector knowing  $\mathbf{B}_{mes}$  on a set of measurement

points in the air. A classical approach would be to use a singular value decomposition (SVD) like proposed in [2]. In this work, we propose a more efficient way consisting in using a statistical Bayesian approach in order to guide the charge repartition. We solve [3]:

$$\mathbf{Q}_{map} = \mathbf{Q}_0 + (\mathbf{A}^t \mathbf{S}_m^{-1} \mathbf{A} \mathbf{S}_0^{-1})^{-1} (\mathbf{A}^t \mathbf{S}_m^{-1}) (\mathbf{B}_{mes} - \mathbf{A} \mathbf{Q}_0) \quad (2)$$

where,  $\mathbf{Q}_{map}$  is the solution,  $\mathbf{Q}_0$  the a priori solution,  $\mathbf{S}_0$  the associated covariance matrix resulting from statistical study introducing uncertain parameters in the direct model.  $\mathbf{S}_m$  is a covariance matrix containing model and measurements uncertainties. To obtain  $\mathbf{S}_0$ , the Monte-Carlo method is used. It involves random selections of input parameters such as external field and the magnetic permeability. The forward problem is solved numerically for each set of input parameters and the charge distribution is statistically analyzed. 10,000 computations are used to compute the covariance.

## IV. RESULTS

Numerical measurements are generated on four tri-axis sensors placed at each corner of a square sheet (white points on Fig.1). Noise measurement is added with the matrix  $\mathbf{S}_m$ . The inverse problem is then solved with a SVD and with the Bayesian approach (Fig.1). Results of inversion are widely improved with the Bayesian approach, which makes fluxes distribution match with the reference, and the extrapolated signature very accurate (Table 1). An experimental validation will be exposed in the extended paper.

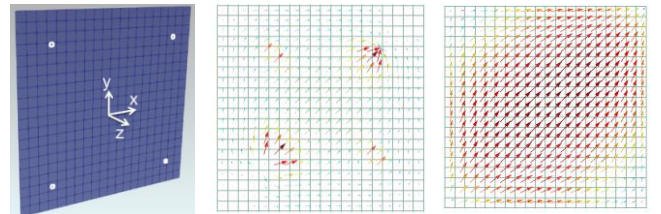


Fig 1: Iron sheet mesh and inversion tests configurations (440 elements, 760 unknowns, thickness: 2 mm, 4 tri-axis sensors at 1 cm from the sheet). Left: mesh and sensors location. Middle:  $\mathbf{B}$  distribution with SVD inversion. Right:  $\mathbf{B}$  distribution using the Bayesian approach.

Induction components	$\mathbf{B}_x$	$\mathbf{B}_y$	$\mathbf{B}_z$
Mean error %	0,56	0,73	0,67
Max error %	2,18	2,24	2,09

Table 1 : Errors computed between the reference and the state identified with the Bayesian approach on a verification line at 0.5 m far from the sheet.

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