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# Inverse Problem Approach to Characterize and Model Magnetization Changes in a Thin Shell Structure Undergoing Magneto-Mechanical effects

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**Abstract** — Measurement of magnetization  $\mathbf{M}$  inside a complex ferromagnetic geometry cannot be achieved by usage of any measurement device. In this paper, we propose to use an inverse problem algorithm to determine the law of variation of  $\mathbf{M}$  for such structures, accounting for the magneto-mechanical effects it is undergoing. The analytical law obtained leads to an intrinsic characterization model of magnetization inside the structure. Validation of the results is achieved on a prototype undergoing high mechanical stresses in low magnetic field, by comparison of the predicted magnetic signature in the vicinity of the prototype, and measurements performed by external magnetic sensors.

## I. ORIGINALITY OF THE STUDY

To anticipate magnetization variations due to stress, some models can be found in literature but applications generally deal with simple shapes, free of demagnetizing field effects, such as rods, undergoing low mechanical stress levels, in a high magnetic field. In addition, the main mechanical stress is usually applied in the same direction as the field.

In our application, high mechanical stresses are applied to a thin complex ferromagnetic geometry under low magnetic fields of any direction. In this case, because of demagnetizing field, magnetization  $\mathbf{M}$  is no more homogeneous and cannot be simply measured. For this reason, to characterize magnetostriction, our interest has been first focused on a global feature: the external magnetic induction  $\mathbf{B}$  measured by magnetic sensors outside the ferromagnetic body. It was previously shown [1] that, for thin shells, the evolution law of  $\mathbf{B}$  was necessarily the same as for  $\mathbf{M}$ . This result was validated on a ferromagnetic cylinder undergoing an internal increasing pressure. An analytical solution to Jiles Law of Approach [2] was also successfully found to accurately model the evolution of  $\mathbf{B}$  with stress, in the case of a vertical inductor field [1]. This dual approach has been recently generalized to any field direction, when stress and field are no more parallel, and presented in another paper [3].

Our goal is now to characterize the magnetization  $\mathbf{M}$  inside the material. Since  $\mathbf{M}$  cannot be directly measured with our geometry, our original approach is to solve an inverse problem: Locapi, an inverse algorithm developed in our laboratory [4], has been used to achieve this. In the paper, the experimental set-up and the method of inversion are presented. It is shown [1,3] that models representing the external induction variations with stress can be extrapolated to model the intrinsic magnetization law. Model results are compared to the magnetization reconstructed by Locapi and discussed.

## II. GENERAL APPROACH AND APPLICATION TO A CYLINDER

The experimental set up consists of a magnetic cylinder subjected to an increasing internal pressure up to 100 bars, under a constant applied induction  $\mathbf{B}_0$ , of any direction.

Nearby triaxial sensors take  $\mathbf{B}(\sigma, \mathbf{B}_0)$  measurements. Inversion runs are then performed on  $\mathbf{B}(\sigma, \mathbf{B}_0)$ , for increasing values of stress  $\sigma$ , providing knowledge of the distribution of magnetization  $\mathbf{M}(\sigma, \mathbf{B}_0)$  at any point inside the device, for successive values of  $\sigma$ . For a vertical inductor field, the measured anhysteretic magnetization  $\mathbf{M}_{anh}$  being independent from  $\sigma$ , an analytical solution to the Jiles equation is:

$$\mathbf{M}(\sigma, \mathbf{B}_0) = \mathbf{M}_{anh}(\mathbf{B}_0) + [\mathbf{M}(0) - \mathbf{M}_{anh}(\mathbf{B}_0)]e^{-\sigma^2/2E\xi} \quad (1)$$

For a longitudinal inductor field, a modified version of this law is derived, taking into account the variations of  $\mathbf{M}_{anh}$  with stress.  $E$  is the Young's modulus, and  $\xi$  an intrinsic parameter of the material, which needs to be determined by fitting, using inversion results.

It is remarkable to notice that these intrinsic laws are the same as the laws found for modeling external induction  $\mathbf{B}$  measurable in the vicinity of the shell [3]. In addition, the value found for parameter  $\xi$  was the same as in [3], where the study was focused on induction  $\mathbf{B}$ . This result shows that  $\xi$  is indeed an intrinsic parameter of the material.

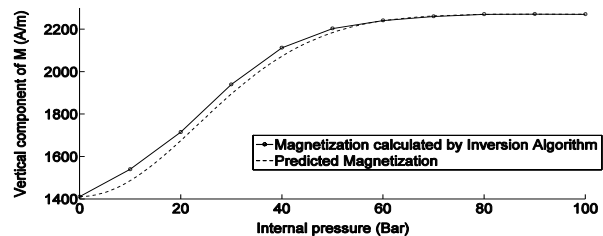


Figure 1: Predicted and measured magnetizations for a ferromagnetic cylinder in a vertical inductor field  $B_0=40\mu\text{T}$  (vertical components).

## III. CONCLUSION

Comparison between models and inversions based on measurements gave very good results for vertical and longitudinal inductor fields (see Fig. 1 in the vertical case). In addition, it has been shown that  $\mathbf{M}$  is a linear function of the applied field in the low field range  $[0,80] \mu\text{T}$ , allowing numerical prediction of magnetization  $\mathbf{M}$  for any both vertical and longitudinal inductor fields in that magnitude range.

## IV. REFERENCES

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