Analytical Model for External Induction Variations of a Ferromagnetic Cylinder Undergoing High Mechanical Stresses in a Low Magnetic Field of any Orientation

Antoine Viana, Laure-Line Rouve, Gilles Cauffet, Jean-Louis Coulomb

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A.Viana, L-L. Rouve, G. Cauffet, J-L. Coulomb
Grenoble Electrical Engineering Lab, Université de Grenoble, (Grenoble-INP, UJF, CNRS UMR 5269), BP 46
38402 Saint Martin d'Hères, France
antoine.viana@g2elab.grenoble-inp.fr

Abstract— This paper introduces an original approach for modeling the external induction variation of a complex ferromagnetic structure undergoing magneto-mechanical effects. From the Jiles Law of Approach that describes the intrinsic magnetization changes due to magnetostriction, an expression of the law in terms of conveniently external measurable induction B is derived for thin ferromagnetic devices. Based on measurements of induction performed by external sensors on an internally pressurized cylinder, an analytical model is found. This model is then tested for any orientation of the magnetic field with respect to stress, from parallel to orthogonal.

I. General Approach

Our aim is to anticipate the magnetic induction B measured outside a cylinder, undergoing internal pressure. Several magnetostriction models can be found in literature. The model developed by Jiles [1] seems particularly well suited to our approach. This model clearly stems that under stress, magnetization **M** tends towards its anhysteretic value. However, direct measurement of **M** cannot be achieved for a complex geometry, such as a hollow cylinder. For this reason, in this study, we focus on an easier measurable physical quantity, the external induction **B**. A dual approach of this problem, based on the intrinsic magnetization **M** study is presented in another paper [2].

Using results developed in [3], the Jiles Law of Approach can be reformulated, for thin shells, in terms of external induction **B** rather than in magnetization **M**. This is an important result since the use of triaxial magnetic sensors located in the vicinity of the shell allows a direct and convenient access to this quantity.

II. Experimental Protocol

The experimental set up consists of a magnetic hollow cylinder subjected to an increasing internal pressure up to 100 bars, under a constant applied induction $\mathbf{B_0}$. Triaxial magnetic sensors, close to the shell, perform external induction $\mathbf{B}(\sigma,\mathbf{B_0})$ measurements (Fig. 1).

First, a characterization of the anhysteretic inductions of the pressurized cylinder is performed, for several pressure levels, and under low applied inductions (less than 80 µT), either vertical or longitudinal. This approach is original since most papers generally deal with the case where stress and magnetic fields are only parallel.

For a vertical applied induction $\mathbf{B_{0V}}$, measurements showed that the anhysteretic induction is independent from stress. Consequently, an analytical solution to the Jiles equation can be found, requiring the knowledge of one physical parameter ξ, determined by a fitting procedure [4].

For a longitudinal applied induction $\mathbf{B_{0L}}$, anhysteretic induction is stress dependant and an exact analytical solution is no more available. Nevertheless, an analytical approximation of the solution is proposed, requiring the knowledge of 2 additional linear terms

Finally induction variation measurements were obtained when the cylinder was submitted to an increasing pressure, under a sum of both vertical and longitudinal fields $\mathbf{B_{0V}}+\mathbf{B_{0L}}$. Results showed that the measured induction was the sum of individual external induction performed with the decoupled fields $\mathbf{B_{0L}}$ then $\mathbf{B_{0V}}$. Consequently, the 2 previous analytical models we found can be used in order to predict induction change for any applied field $\mathbf{B_{0V}} + \mathbf{B_{0L}}$.

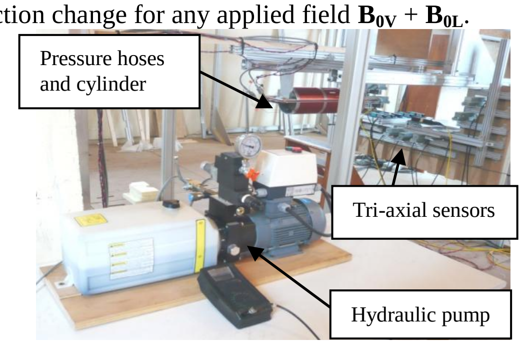

Fig. 1: Experimental set-up located in the LMMCF - Grenoble - France

III. Validation on a Pressurized Cylinder in Low Field

Previous results were used to model the external induction variation due to the cylinder under increasing stress and various induction values and orientations: $\mathbf{B_L}$=40µT, $\mathbf{B_V}$=40µT + $\mathbf{B_L}$=20µT, etc. Comparison between models and measurements presents a relative error less than 5% (see Fig. 2 for the longitudinal case).

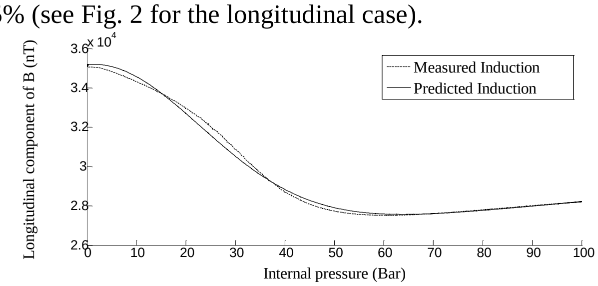

Fig. 2: Comparison between modeled and measured longitudinal components of induction B in a longitudinal induction B_L=40 µT

IV. References

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