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Electromagnetic Methodology for Mechanical Stress Evaluation of Anisotropic Ferromagnetic Materials

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Abstract. This work presents an electromagnetic method for mechanical stress evaluation using a U-shaped eddy current (EC) sensor. This technique exploits the magneto-elastic constitutive laws of ferromagnetic materials. Observing the sensor impedance provides information on both the initial magnetic anisotropy and the stress-induced magnetic anisotropy. Measurements from API-5L X52 steel pipelines in the longitudinal (DL) and transverse (DT) directions are used to validate this methodology.

Keywords. Magneto-elastic coupling, Eddy current non-destructive testing, anisotropy, API-5L X52.

1. Introduction

In this paper the EC non-destructive testing using a U-shaped sensor (Fig. 1.a) is employed to detect mechanical stress \mathbf{T} in anisotropic ferromagnetic material. For a magneto-dynamic problem, the key parameter to include the stress effect is the magnetic permeability μ [1]. μ is sensitive to stress [2], and the electrical conductivity is assumed constant within an applied stress range from 0 MPa to 160 MPa [3]. Therefore, any variation of the measured impedance signal is from magnetic properties once the lift-off is constant.

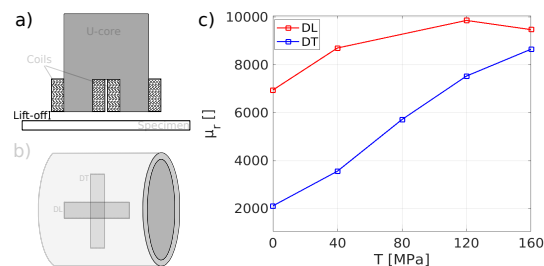


Figure 1. a) Sensor geometry. b) Schematic of specimens cut-out. c) μ_r of DL and DT specimens under stress.

2. Stress effect on the EC sensor impedance

The magneto-elastic characterization of two specimens extracted from an API-5L X52 pipeline¹ in the directions DL and DT Fig. 1.b, shows that the material is anisotropic and that $\mu_r(\mathbf{T})$ increases with respect to uni-axial tensile stresses(Fig. 1.c). Thus the sensor impedance depends on stress. Using a U-shaped EC sensor provides information on the direction of the initial magnetic anisotropy as well as the direction of the induced magnetic anisotropy from uni-axial stresses (Fig. 2). The anisotropy can be estimated by comparing the measured sensor impedance $Z_\theta(\mathbf{T})$ to a reference impedance Z_0 to calculate the relative variation $|\Delta Z_\theta(\mathbf{T})|$, where θ is the angle between the uniaxial stress direction and the sensor orientation, and Z_0 is the impedance for an unstressed material at $\theta = 0$.

3. Results

Z_0 is measured after demagnetizing the specimen. Then a frequency sweep of the impedance is performed for each stress state. Good sensitivity was found for anisotropy detection (Fig. 2.a) and stress evaluation (Fig. 2.b); however, the latter depends on material magnetization M_r . A numerical model of impedance computation will be included in the extended version.

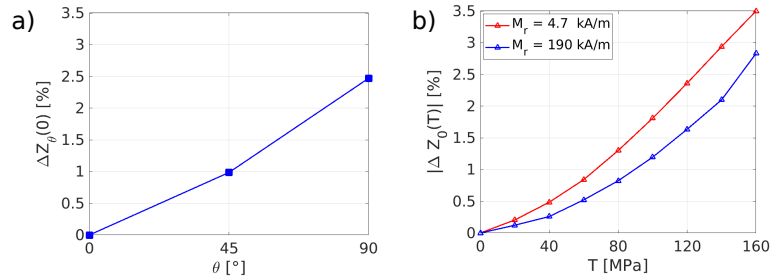


Figure 2. Magnetic anisotropy evaluation at 180 kHz. a) Initial magnetic anisotropy in DL. b) Stress-induced magnetic anisotropy in DL.

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¹The specimens were provided by GRTgaz Research & Innovation Center for Energy. Address: 1-3 rue du commandant d'Estienne d'Orves, 92390 Villeneuve La Garenne, France.