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# Electromagnetic Methodology for Mechanical Stress Evaluation of Anisotropic Ferromagnetic Materials

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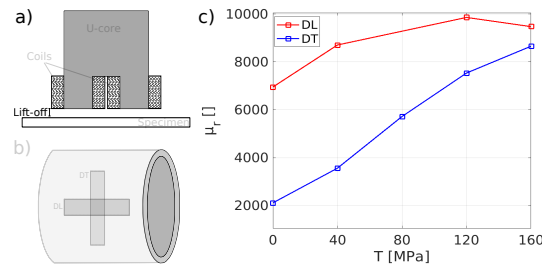
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**Abstract.** This work presents an electromagnetic method for mechanical stress evaluation using a U-shaped eddy current (EC) sensor. This technique exploits the magneto-elastic constitutive laws of ferromagnetic materials. Observing the sensor impedance 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  $T$  in anisotropic ferromagnetic material. For a magneto-dynamic problem, the key parameter to include the stress effect is the magnetic permeability  $\mu$  [1].  $\mu$  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.



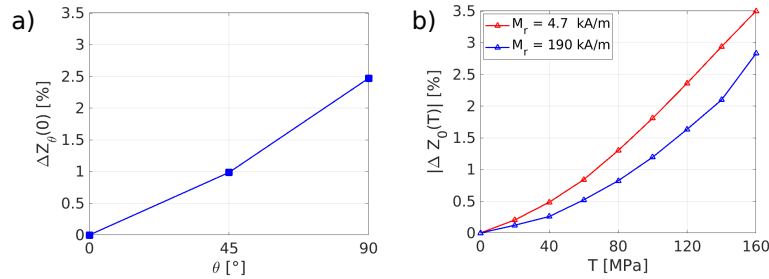
**Figure 1.** a) Sensor geometry. b) Schematic of specimens cut-out. c)  $\mu_r$  of DL and DT specimens under stress.

## 2. Stress effect on the EC sensor impedance

The magneto-elastic characterization of two specimens extracted from an API-5L X52 pipeline<sup>1</sup> 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  $\theta$  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.

## References

- [1] A. Dahia, E. Berthelot, Y. Le Bihan, and L. Daniel, "A model-based method for the characterisation of stress in magnetic materials using eddy current non-destructive evaluation," *J. Phys. D: Appl. Phys.*, vol. 48, 195002 (2015).
- [2] B. D. Cullity, C. D. Graham, Introduction to magnetic materials, 2<sup>nd</sup> edition, Wiley, New Jersey, 2011.
- [3] M. Morozov, G. Yun Tian, and P. J. Withers, "The pulsed eddy current response to applied loading of various aluminium alloys," *NDT & E Int.*, vol. 43, pp. 493–500 (2010).

<sup>1</sup>The 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.