Dynamic hysteresis lump model including fractional operators for the incremental permeability nondestructive testing

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Abstract. Magnetic Incremental Permeability (MIP), represents the effective permeability for a small alternating field superimposed on a larger steady field. A dynamic lump scalar hysteresis model including fractional operator is proposed here to model MIP. The model considers both tangent excitation field *H* and permanent mechanical stress *T* as excitation of the material. Numerical results and simulation parameters (fractional order) allow to clarify the MIP mechanisms and to define degradation threshold level for industrial applications.

1 Introduction

The numerical scheme we use to model *MIP* is a lump model including two contributions (quasi-static and dynamic) and it operates with *H* and *T* as inputs.

2 Model

2.1 Quasi-static contribution

Quasi-static contribution is observable when plotting the spontaneous average magnetic induction field, *B*, versus the surface magnetic excitation field, *H* for very low frequency (f<<1Hz in typical soft magnetic material). Among different approaches for the simulation of the quasi-static hysteresis behavior [1], Preisach's model exhibits the interesting property to switch from *H* to *B* as input of the quasi-static hysteresis model. Preisach model, widely used to describe the hysteresis phenomenon in magnetic materials [1], assumes that the material magnetization is determined by the contribution of a set of elementary hysteresis loops having a distribution function over the Preisach's triangle. In order to model precisely the magnetic material behavior, it is necessary to accurately determine the Preisach's distribution function from experimental data. The method employed in this study discretizes the distribution function in a finite set of values which are determined by suitable experimental data.

2.2 Dynamic contribution

Under weak frequency conditions, scalar quasi-static lump hysteresis models provide accurate results for the evolution of the average magnetic induction *B* versus magnetic excitation field *H*. Unfortunately as soon as the quasi-static external conditions expire, huge differences appear. Small improvements can be obtained on a narrow frequency bandwidth by adding to this lump model a simple dynamic contribution, product of a damping constant to the time domain derivation of the induction field *B*. Much better improvements can obtained by replacing the first order time derivation by a fractional order [2]. Fractional derivation generalizes the concept of derivative to complex and non-integer orders. In our numerical scheme, fractional order provides new degree of freedom that can be adjusted to fit with the experimental data on a large frequency bandwidth. Considering both static and fractional dynamic contributions, the final version of the model is resumed in first equation:

$$\rho.\frac{d^n B(t)}{dt^n} = H_{dyn}(t) - f_{static}^{-1}(B(t)) \tag{1}$$

2.3 Mechanical stress consideration

MIP signatures are highly mechanical stress dependent. *MIP* constitutes a particularly interesting tool for the observation of residual stress due to fatigue and ageing. To obtain accurate numerical simulations of *MIP*, mechanical stress consideration must be precisely taken into account. Experimental results have shown that the induction *B* falls under compressive stress. For reasons of physical symmetry, the mechanical stress *T* can be introduced in the model as an equivalent excitation field H (*F* = applied force => *H* = *h(B).T*). The function *h(B)* specifically enables the translation of symmetry described above, and must be an odd function, wherein *h(B)* = *αB* can be used and α fitted from experimental measurements. The relation between mechanical and electrical excitation is established and a new modified version of equation (1) is proposed:

$$H_{equ} = \alpha.T.B, \qquad \rho.\frac{d^n B(t)}{dt^n} = H_{dyn}(t) - \alpha.T.B - f_{static}^{-1}(B(t)) \tag{2}$$

α is a material characteristic, independent of the sample geometry and determined by comparison of measurements/simulations.

3 Numerical result and conclusion

Figure 1 illustrates the model accuracy. We plot here the evolution of the *RMS* permeability versus *H* for a free sample and a stressed one (200N/mm^2). These numerical results can be compared with success to the experimental results published by G. Dobmann in [3].

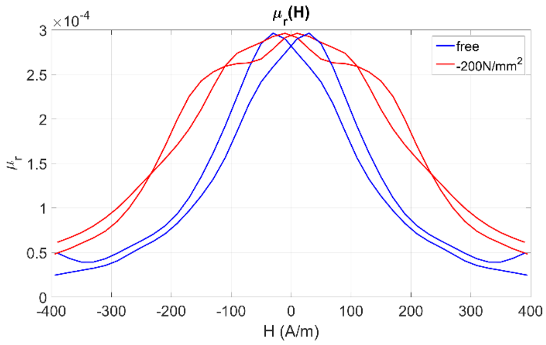

Fig. 1 – Evolution of the RMS permeability versus the excitation field H for a free sample and a stressed one.

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