Thermal Behavior of Iron-Nickel-Chromium Alloys and Correlation with Magnetic and Physical Properties-Part B: Dynamic Modeling

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In the present study, we illustrate the results of a developed frequency and temperature dependent model of hysteresis. The model is validated on a NiCrFe (50% of Ni) material by comparing simulated curves with the experimental ones. The proposed model generates a meaningful set of parameters and the variation of both static and dynamic model parameters versus temperature are correlated with magnetic and physical properties of the material.

***Index Terms*— Characterization, Dynamic hysteresis, Jiles-Atherton static model, Magnetic materials, Modeling, Resistivity, Temperature.**

I. INTRODUCTION

THE AIM of this work is to model the thermal and dynamic behavior of a ferromagnetic material and correlate the variation of the model parameters with magnetic and/or physical properties.

Table 1 displays some magnetic and physical properties of the investigated alloy given by the supplier [1].

TABLE I
SOME PROPERTIES OF THE INVESTIGATED ALLOY

Reference	Chemical composition (Weight %)	B_s (T)	T_c (°C)	Resistivity (µΩ.cm)
Phytherm 260	Ni(50)Cr(9)Fe(Bal)	0.83	280	100

II. THE DYNAMIC STATIC FEEDBACK MODEL: SIMULATION OF THE THERMAL BEHAVIOR

1) *Global Dynamic Model*

Fig.1 shows the measured and calculated hysteresis loops in the Phytherm260 alloy at 50Hz for temperatures ranging from the room temperature to near the Currie point. The Dynamic model used in simulations is based on the resolution of the differential expression given in Eq.(1) [2].

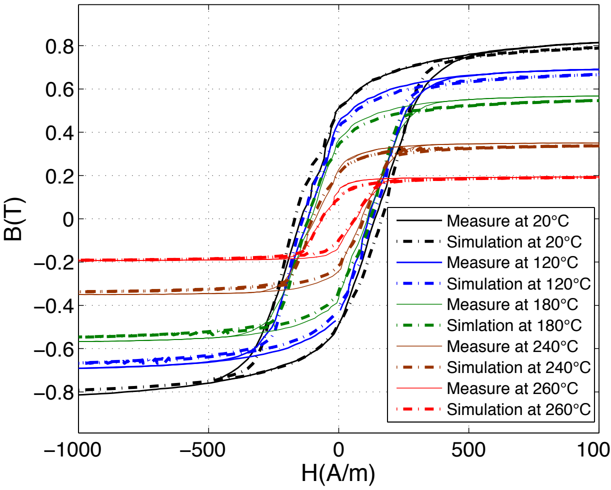

Fig. 1. Measured and simulated hysteresis loops at 50Hz in the Phytherm 260 alloy for various temperatures

$$\frac{dB}{dt} = \frac{1}{\gamma}[H - Hstat(B)] \qquad (1)$$

B represents the average induction in the cross section; *H* is the applied excitation field and the *Hstat*(*B*) term is a value calculated from a static hysteresis model.

The dynamic effects are taken into account by introducing the γ parameter. The model is quite accurate under the assumption of negligible skin effect.

It should be noted that a static hysteretic model is introduced in the main formulation Eq.(1). In our case, we have used a new static J-A temperature dependent model. Indeed, in a recent work [3], we have developed a new temperature dependent model of static hysteresis based on an extension of modified Weiss and Jiles-Atherton theories. The modified Weiss law is used in the existing J-A model to express saturation magnetization, M_s and the molecular field parameter, α as functions of temperature. The other three parameters of the J-A model: domain density, *a*, pinning factor, *k* and reversibility, *c* at any temperature are identified from the measured data using suitable algorithms.

The proposed model generates meaningful sets of J-A parameters. Simulations are compared to quasi-static measurements made on two iron-nickel-chromium soft magnetic alloys and the results are in good agreement.

The parameter γ is identified from dynamic experimental measurements using suitable algorithms (see Fig.4). Fig.4.

Fig.1 shows good agreement between the simulated loops using the global dynamic model and the experimental curves.

III. EXPERIMENTAL MEASURMENT OF THE ELECTRICAL RESISTIVITY WITH TEMPERATURE

In order to investigate the correlation between γ parameter and the resistivity we have performed the experiment shown in Fig. 2.

Based on a four-point probe measurement method, the temperature dependence of the electrical resistivity of a toroid specimen is determined experimentally over the temperature range. The "voltage" probes are arranged at an angle of 45° from "current" terminals. As current flows between "current" electrodes connected to a current supply, the voltage drop

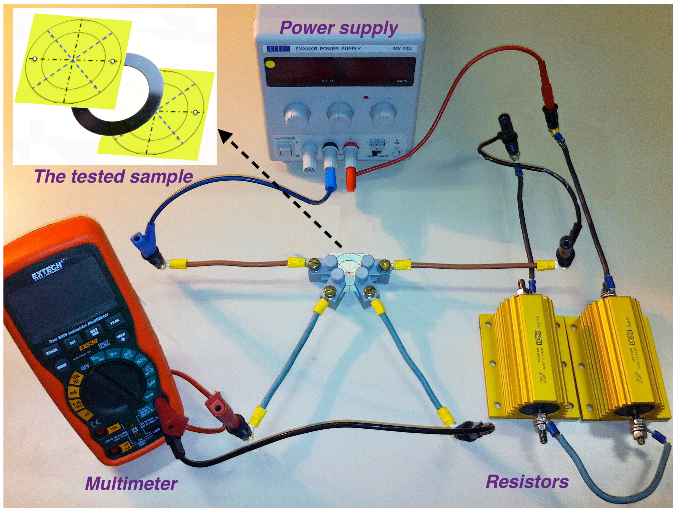

Fig. 2. Method of measurement of the electrical resistivity.

across the “voltage” probes is measured using an accurate multimeter. The average of the results of voltage measurements along the sample perimeter at 45° is considered at each temperature. The relationship of the current and voltage values depend on the resistivity of the material under test and geometrical characteristics.

Figure 3 shows the variation of the electrical resistivity of the tested sample versus temperature. At room temperature, our measured value of resistivity is equal to 1.02×10^{-6} Ω.m. We can note that this value corresponds quite well to that given by the supplier (see Table I). These data are compared in the same figure to the analytical expression of resistivity as a function of temperature in Eq. (3) by fitting to the measured data. ρ_0 is the resistivity at 0 °C, α is the thermal coefficient of the material and θ is the temperature in Celsius degrees. The estimated values of ρ_0 and η are respectively 1.0042×10^{-6} and 6.2809×10^{-4}.

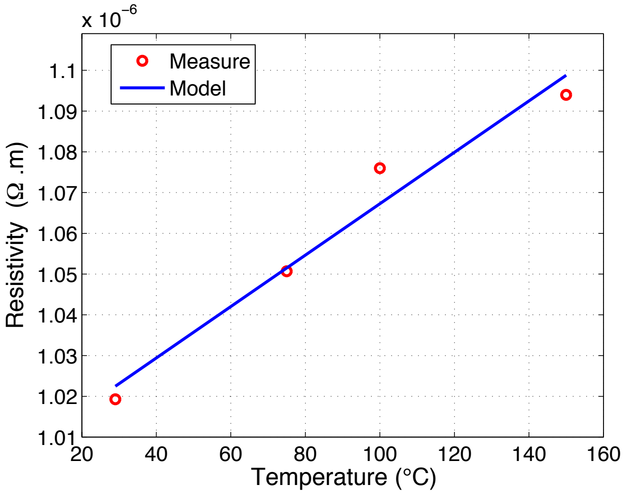

Fig. 3. Measured and simulated resistivity as a function of temperature

$$\rho = \rho_0 .(1+\eta.\theta) \qquad (3)$$

The variation of γ parameter versus temperature is correlated with the variation of resistivity by plotting the measured and simulated $\sigma d^2/12$ term in Fig.4 ($\sigma = 1/\rho$).

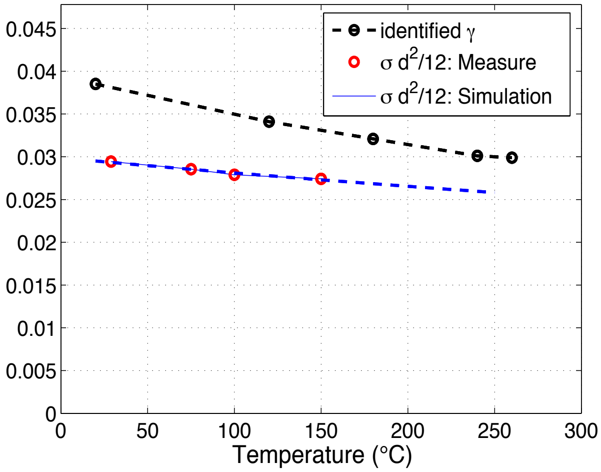

Fig. 4. Variation of the parameter of the dynamic model with temperature and correlation with resistivity

IV. DISCCUSION

As experiments show and referring to the works of Bertotti [4], we propose a method for identifying the γ parameter in order to obtain the same energy due to wall motion as predicted by Bertotti. To satisfy this condition, the excess energy of the two models should be equal; which leads to write:

$$\gamma = \frac{\sigma d^2}{12} + \lambda$$

σ =the electrical conductivity, d is the thikness of the sample. Thus, the first term of γ represents the dynamic effects due to eddy currents and the second one defines the wall motions within the material.

In Fig.4, the apparent difference between the identified γ and $\sigma d^2/12$ represents the λ parameter. The question we ask is about the evolution of λ with temperature. Further consideration will be given to this question in the extended paper in order to propose a general predictive method of the dynamic parameter, γ with temperature.

V. CONCLUSION AND PROSPECTS

In the proposed study, a frequency and temperature dependent model of hysteresis is presented. It is validated on a NiCrFe (50% Ni) material by comparing measured and simulated B-H curves. The variation of the dynamic model γ parameter versus temperature is correlated with a physical property of the material (“conductivity”). Further explanations and developments will be given in the extended paper.

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