Determination of Parameters in the Jiles - Atherton Model for Measured Hysteresis Loops

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Abstract. *The Jiles-Atherton model of a hysteresis loop enables us to capture the behaviour of a magnetic material at the level of domains. At present, the model finds a large number of applications, for example in Spice simulators, where it facilitates the description of the behaviour of a core made from a magnetic material. The paper contains a discussion of constraints related to the original algorithm for the calculation of the model parameters and presents the results obtained via the least-squares method. Based on the measured typical behaviour of hysteresis loops (rounded and flat), we calculated the error between the measured and the calculated loops. To facilitate better approximation of the measured loop, the original computation model was modified, and the acquired results are presented within this article.*

Keywords: Hysteresis Loop, Jiles - Atherton Model, Magnetic Measurements.

1. Introduction

The laboratory of magnetic measurements at the DTEEE (Fig. 1, left) supports fully automated measurement of hysteresis loops. Real parameters of the examined materials can be measured on both open and closed samples, which enables us to record the behaviour of the materials at a point very close to operating use and conditions. Thanks to the applied high-quality fluxmeter, it is possible to select for the measurement of a quasi-static hysteresis loop a suitably long measuring period to ensure the suppression of the effect of eddy currents. Fig. 1 (right) shows that, in the measured toroidal sample of the Behanit material, it is necessary to select the measuring period of up to 80 s; given this precondition, the measured coercivity satisfactorily approached (in the limiting manner) its static value. The measured data are processed in the Matlab program (via a PC), and the calculated hysteresis value is corrected with respect to the systematic errors that occur during the measurement. A detailed description of certain elements of the process, for example correction of the fluxmeter zero, is provided by reference [1].

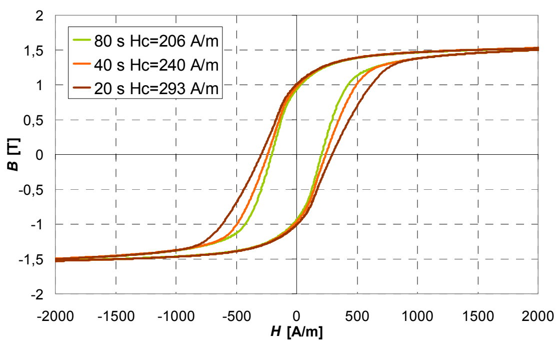

Fig. 1. The laboratory of magnetic measurements at the DTEEE, left; effect of the measured period length upon the measured hysteresis loop of the Behanit material and the resulting requirements placed on the fluxmeter, right.

To optimize the magnetic circuits, is necessary to create, based on the measured data, a suitable mathematical model of the hysteresis loop. With respect to the less intensive computation requirements and the possibility of application in Spice programs, we selected the Jiles - Atherton hysteresis loop model.

2. The Jiles – Atherton Hysteresis Loop Model

The basic equation for this model consists in the formula describing the behaviour of a magnetic material at the level of domains [2]. This formula provides a differential description that changes the output according to variation in the direction of the input value , namely the magnetic field intensity. The total magnetization M is then given by the formula:

$$M = M_{irr} + M_{rev} \tag{1}$$

where M_{irr} is the irreversible magnetization and M_{rev} denotes the reversible magnetization. With any magnetization change, there occur irreversible shifts defined according to

$$\frac{\mathrm{d}M_{\mathrm{irr}}}{\mathrm{d}H} = \frac{M_{\mathrm{an}} - M_{\mathrm{irr}}}{k \cdot \delta - \alpha\left(M_{\mathrm{an}} - M_{\mathrm{irr}}\right)} \tag{2}$$

In the above-shown relation (2), M_{an} and M_{irr} denote the anhysteretic and irreversible magnetization, respectively, k is the parameter determining the widening of the curve, δ is the sign parameter, and α is the molecular field parameter. The sign function follows the variation of the magnetic field intensity direction and is therefore given by the formula:

$$\delta = \left\langle \begin{matrix} +1 \; pro \; dH/dt > 0 \\ -1 \; pro \; dH/dt < 0 \end{matrix} \right. \tag{3}$$

Anhysteretic magnetization is an idealized process in which no errors occur in the crystal lattice during magnetization. Thus, the course of the process is given by the shift of the domain walls and the displacement of the spontaneous magnetization of these domains in the direction of the external field. This relation is most often expressed by the Langevin function in the form:

$$= M_{\mathrm{sat}} \cdot \left[\coth\left(\frac{H + \alpha \cdot M}{a} \right) - \frac{a}{H + \alpha \cdot M} \right] \tag{4}$$

where M_{sat} is the saturation magnetization and a denotes the shaped, temperature-dependent parameter. The parameter assumes values in the order of approximately 10^{-3} to 10^{-7}. However, the relation of anhysteretic magnetization may generally be indicated by any monotonously growing function, and it is also possible to use the measured curve. The last part of the formula (1) consists in reversible magnetization; in the model, this magnetization is expressed as the difference of the anhysteretic and the irreversible magnetization. This difference is reduced to

$$M_{\mathrm{rev}} = c \cdot \left(M_{\mathrm{an}} - M_{\mathrm{irr}}\right) \tag{5}$$

where the parameter c is from the interval $0 < c < 1$.

3. Identification of the Jiles - Atherton model in selected materials

For the calculation, we need to use an iteration method and apply suitably chosen initial coefficient values. The iteration procedure presented by basic reference [2] does not converge for certain hysteresis loops, as noted by the authors of source [3]; this claim was verified during the calculation of the flat hysteresis loop of a nanocrystalline material. For this reason, we used the least-squares method utilizing only the initial estimation indicated by [2].

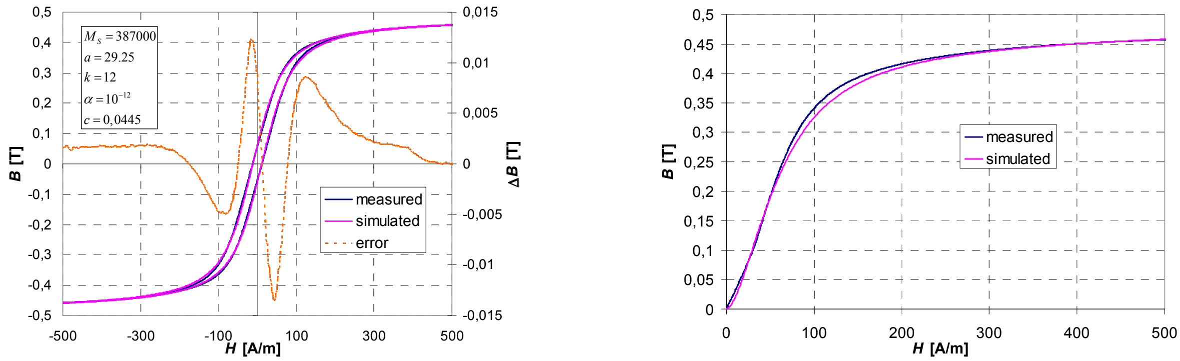

Fig. 2. The measured and simulated hysteresis loop of the 3C90 ferrite, left; the initial magnetization curve, right

The results for the 3C90 ferrite and the correct definition of the initial magnetization curve are both shown in Fig. 2.

If the Langevin function is applied to a material with a flat hysteresis loop having a sharp elbow such as required in, for example, switching forward converters, the approximation does not give satisfactory results. We measured the promising VITROPERM 500F nanocrystalline material. Its approximation for the least sum of the deviation squares is shown in the left section of Fig. 3; the right section of the figure then indicates the condition that, in H_{max}, the simulated hysteresis loop does not exceed the value of B_{max}. Here, it is obvious that the model does not capture correctly the shape of the hysteresis loop in the elbow and generally exhibits higher initial permeability. The limitation to B_{max} has proved beneficial for lower excitation levels.

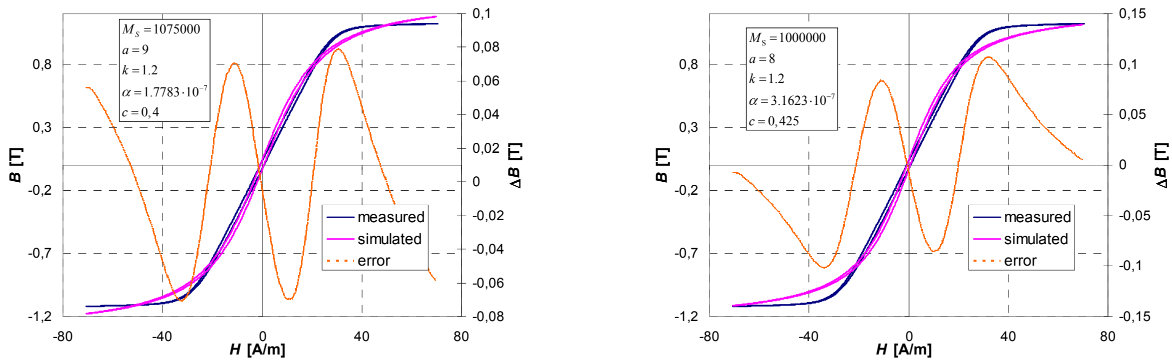

Fig. 3. The VITROPERM 500F hysteresis loop, left; with the B_{max} constraint, right.

Better consistency between the simulations and the measured hysteresis loop can be achieved if the parameter in the formula (2) is separated from the parameter in the Langevin function as present in the equation (4). With the model thus widened, better inclination of the hysteresis loop can be ensured.

The simulation of a hysteresis loop can be most faithfully captured using the measured curve of anhysteretic magnetization. As the measurement of the curve requires special behaviour of the magnetizing current [3], its course was estimated from the mean value of the measured hysteresis loop graphically. Despite this deficit, the achieved results are very good; the relative error between the measured and the simulated boundary hysteresis loops did not exceed 1%. A comparison between the measured and the simulated loops for unipolar excitation is shown in Fig. 5.

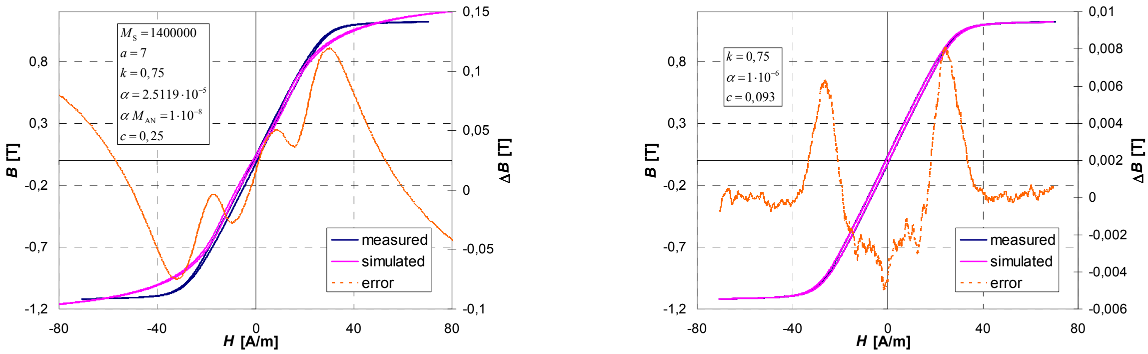

Fig. 4. The hysteresis loop for the separation of α parameters (left) and for the given behaviour of M_{man} (right)

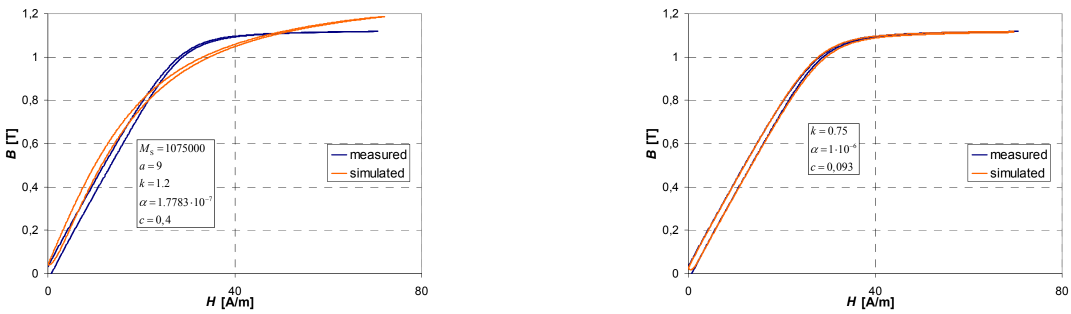

Fig. 5. Fig. 3. Unipolar excitation of VITROPERM 500F for the Langevin function (left) and for the preset antihysteretic curve (right).

4. Conclusions

The authors present a discussion of constraints characterizing the Jiles-Atherton hysteresis loop model under the Langevin function-based approximation of the anhysteretic magnetization curve. Further research will be directed towards setting up a system for the measurement of the anhysteretic magnetization curve. The accuracy of the given approximation is well defined by the determination of the difference between the measured and the simulated curves.

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