Application of Preisach Model to Low Loss Ferromagnetic Materials

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Abstract. *Exact and accurate description of ferromagnetic materials for purpose of their modelling, as an instance, is a very difficult task. A general approach is to use the Preisach model. Main problem in the model application is to find the weighting function that is done by material properties. Two methods are presented, how to get the weighting function. The results are similar and agree with experiment, as for technical accuracy.*

Keywords: Preisach Model, Ferromagnetic Materials, Rectangular Hysteresis Loops, Current Measurement of Ferromagnetic Loops, Modelling.

1. Introduction

Materials used in electronics and elements made from them are now modeled by sophisticated methods in order their outputs will be as close as possible to experiment. Since the ferromagnetic materials exhibit hysteresis, their modeling is extremely complicated, irrespective of work made in this area. The most universal model is the Preisach one [1]. The key part of the model is the weighting function that characterizes the magnetic properties of the material. It can be derived from the measurements. The basic theoretical procedure for experimental data processing is presented in literature [1]. However, due to the experimental errors some modifications are necessary. Different attempts are presented, for instance, in [2]. Another approach is to guess the weighting function [3].

A good model of ferromagnetics is not important only in technical praxis, but also in basic research or in the education. In technical praxis, for instance, the transition effects connected with power switching have more than 10 time higher currents than currents predicted from linear models. In material research the weighting function is a full characteristic of material. Other magnetic parameters can be, in principle, derived from it and different materials can be compared using this function. In education the perfect model can simulate all the magnetic effects more clearly and in higher quality than output of the apparatus, irrespective of high price of standard apparatus and necessary experience with its control.

In the paper we describe the Preisach model, we will present the experiment, and we mention the data processing and compare both the approaches for obtaining the weighting function.

2. Theory

According to physical structure the basic unit of the Preisach model is the ideal elementary dipole exhibiting rectangular hysteresis loop with parameters: dipole momentum m_o, low and up magnetic field strengths H_d and H_u, respectively. According to the position of external magnetic field H with respect to H_d and H_u and previous history, the dipole momentum is either $+m_o$ or $-m_o$. Schematic summary of elementary dipoles is in Fig 1a.

Several specific elementary hysteresis loops can be found in Fig. 1a. No hysteresis is on the major diagonal. Symmetric loops are in the minor diagonal. Therefore we can expect the maximum of weighting function on that minor diagonal. On the left hand vertical side the value H_d is fixed. On the contrary, on the upper horizontal side the upper field H_u is fixed.

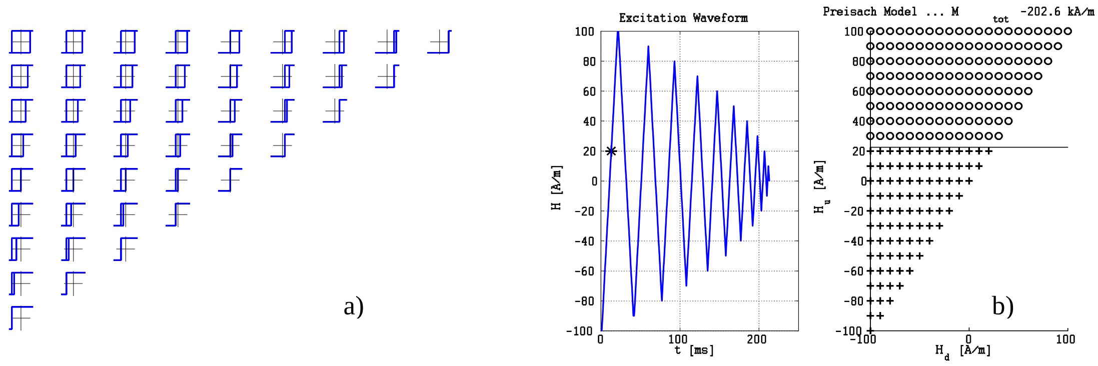

Fig. 1. a) Elementary dipoles as basic elements of Preisach model. b) Application of the model.

The work of Preisach model can be explained simply by geometrical means. The elementary dipoles in the net like that in Fig. 1a are oriented up (represented by plus sign) or down (circles) as in Fig. 1b. Suppose that the sample was polarized down and external field strength *H* increases from minimum value. For selected time instant its position on waveform and its level on Preisach diagram are shown in left and right hand part of Fig. 1b, respectively. The horizontal field level moves in up direction. All elementary dipoles with $H_u < H$ are polarized up. If the external field decreases, the vertical level that moves from right to left is used. The dipole switching is similar, all dipoles with $H_d > H$ are in the down orientation.

Mathematically, the Preisach model for the computation of material magnetic momentum *M* of the specimen (usually magnetization) at time *t* is given by the formula [1]

$$M(t) = \iint_{H_u \geq H_d} w(H_u, H_d) \hat{m}(H_u, H_d) H(t) \, \mathrm{d}H_u \mathrm{d}H_d \, . \qquad . \qquad (1)$$

The hysteresis operator $\hat{m}(H_u, H_d)$ forms the elementary magnetic momentum for given field strength $H(t)$ according to the explanation in Fig. 1, for instance. Therefore, $\hat{m}(H_u, H_d).H(t)$ means either $+m_o$ or $-m_o$. The weighting function $w(H_u, H_d)$ is determined by the material and it should be found.

It is proved in [1] that the weighting function is a partial derivative of momentum function $M(H_u, H_d)$ in (1) by both the field strengths H_u and H_d. Therefore, the momentum function should be known in Preisach triangle in Fig. 1.

In order to ensure simple and stable initial conditions in experiments, the external magnetic field should increase from minimum value to several one (local maximum, which is less than absolute maximum) and then should decrease again to absolute minimum. The curve from local maximum, H_u^*, to absolute minimum is termed the first order transition curve. Some of them are shown in Fig. 2a for the investigated material. The branch corresponding to field increase should be the same for all the transition curves bellow the maximum H_u^* and these curves should lay above it.

3. Experiment and Data Processing

The task of experiment is to get the first order transition curves like those in Fig. 2a. We have used standard full automated experimental apparatus with one modification. Since the current source is necessary we get it from the commercial universal voltage source Kikussui PCR

2000LA by suitable series resistance. More difficult solution was to program the voltage source by specific voltage waveform. However, the current source cannot operate at power net frequency of 50 Hz, since the coil impedance is high and voltage source does not produce required currents. Therefore we decreased operating frequency to 1 Hz, which has brought other problems due to the long time measurement, about 4 minutes,

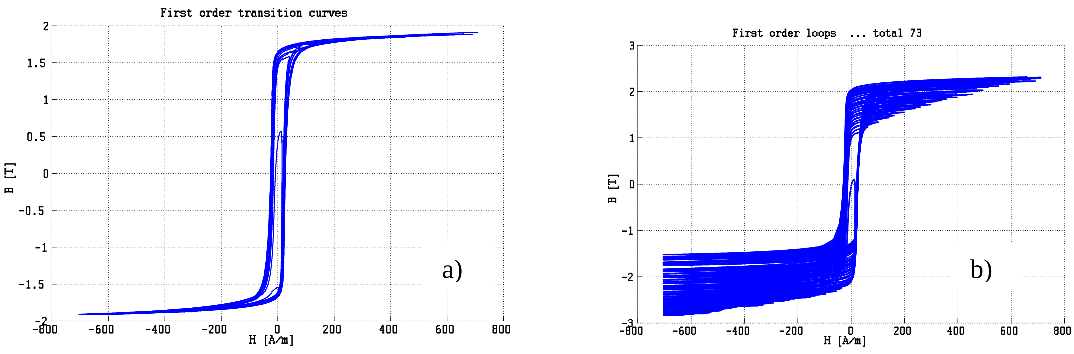

Fig. 2. a) First order transition curves after numeric processing, b) Original curves from experiment..

The induced secondary voltage is low and noise, especially at 50 Hz, distorts the outout waveform. Furthermore, the source produces field strength waveform with deviations near zero crossing. However the integration of the secondary voltage reduces both the effects. On the other hand the low frequency reduces eddy currents losses. Therefore the loops may be closer to ideal ones

Unfortunately, the most important second order effect was the zero drift of the secondary voltage that was due to the measuring chain offset. Although it was almost eliminated at the start of measurement, due to the measurement long time it led to the vertical shift of the transition curves. Typical results from expriment after standard integration are in Fig. 2b. The spread is very high, therefore the data preprocessing is necesssary.

The simple method of preprocessing uses data averaging at the curve start and the vertical shifting, in order to ensure the curve symmery. The effect of this simple data processing can be judged by comparing results in Fig. 2 for original (right) and improved data (left).

Opposite to the simple use of Preisach operator in (1), the determination of weighting function is very complicated. Because of high level noise, the numeric derivation is impossible. There are two basic ways for weighting function determination

1. Guess the weighting function [3].
2. Modify the systematic procedure on experimental data suggested in [1].

The estimation method uses the weighting function in the form of probability density. Three, relative similar distributions were considered: normal, Cauchy and lognormal. Because of symmetry, the centre of weighting function must be on the minor diagonal, where the elementary loops are symmetrical, see Fig. 1a. The loop width then determines the mean value. The only parameter to be found is the standard deviation. Since we considered product of two densities, two parameters are searched. The search is automated by nonlinear programming, by the fminsearch function in MATLAB.

The use of partial derivation needs to approximate the data momentum surface by analytical function of two variables H_u and H_d. We have used the simplest function arctan($k(H - H_o)$) that matches data well, if the range of independent variable contains both positive and negative values. It uses two selectable parameters coefficient k and shift H_o. The approximation is applied in both the directions, horizontal with variable H_d and vertical with variable H_u. The surface formed by magnetic momentum is approximated by a product of these arctan functions with different parameters. Its derivation is similar to Cauchy probability density

4. Results

In this section we present in Fig. 3 the comparison of two approximations: the result of estimation is in Fig. 3a and the systematic method output is presented in Fig. 3b. The agreement with experiment is better for simpler method. It can be explained by automated procedure, while the surface approximation by systematic method was handmade.

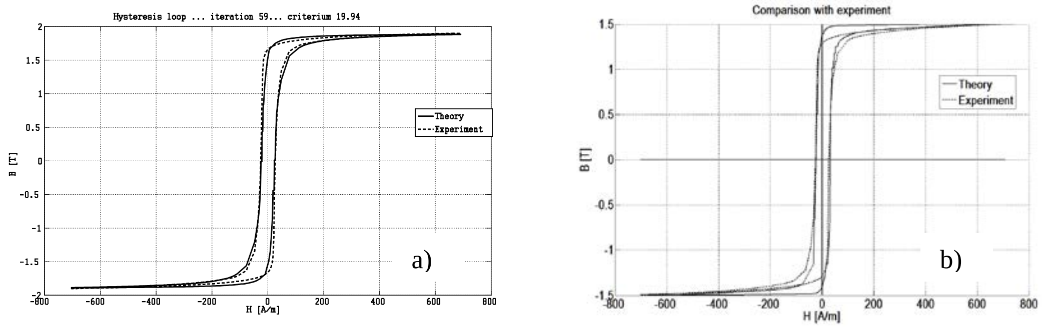

Fig. 3. Comparison with experiment: a) Estimation method, b) Systematic method.

5. Discussion and conclusions

Two methods were used for Preisach model identification with similar results. The estimation method is simpler, needs only one measurement near the saturation and surprisingly leads to better results. In general, the basic limitation of systematic method is a low experimental accuracy and the need to approximate the two-dimensional function (surface). On the other hand it can be successfully applied in all cases. The presented accuracy of modelling is acceptable from the technical point of view, since the difference of magnetic properties in samples from magnetic material can reach almost 10 %.

Future work should be focused both to the experiment and computations. In the experiment the accuracy can be improved by the use of higher frequency (3 or 10 Hz), for instance. In the computation area the automated approximation of the momentum surface should be made.

Acknowledgements

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