Numerical Characterization Method for Magnetic Materials with Hysteresis

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Abstract. The paper presents a numerical method based on Preisach model for the characterization and modelling of hysteretic magnetic materials exhibiting scalar or vector hysteresis, with acceptable accuracy, based on minimal material measurement data.

1 Introduction

In recent years, a renewed interest is observed in the scientific community for the study of materials showing the property of hysteresis which is closely related to a more common application: the process of recording (usually magnetic recording) and the property of memory.

From the modeling point of view, even if many hysteresis models have been developed, only very few are really used systematically in the laboratories and the interest of many scientists have been concentrated to improve them and to develop their ability to cover the most complex behavior observed experimentally in magnetic materials. The models are rarely covering all the range of magnetization processes observed experimentally. Most of them are dedicated simply to describe a hysteresis loop without any link to the physical processes involved.

The Classical Preisach Model (CPM) is one of the most known hysteresis model. If in the field of scalar Preisach models a number of rules and properties have been established (wiping-out, congruency), in the vector modeling these are still at the beginning. Only a few true vectorial Preisach models have been developed but they are numerically too inefficient or do not obey the most simple properties observed experimentally. It is noticed that this domain is becoming more important as in many applications a vector type image of the system is required.

This paper presents a numerical method based on Preisach model for the characterization and modelling of hysteretic magnetic exhibiting scalar and vector hysteresis. The proposed method solves electromagnetic problems involving scalar and vector hysteresis with acceptable accuracy, based on minimal material measurement data.

In the next section are presented details about the proposed methodology for modeling and identification of scalar and vector hysteresis using Preisach model, and obtained numerical results using experimental data.

2 Method of modelling of hysteretic magnetic materials

The Mayergoyz-type extensions of the Preisach model (CPM) [1] represent the optimal solution for phenomenological modeling, especially in view of the practical applicability of the numerical models. The methods belonging to this category offer an optimal balance between the stability of the identification procedure, requirements of experimental data and of computation resources, on one side, and the accuracy of the model, on the other side.

In numerical analysis, it is necessary to solve with acceptable accuracy electromagnetic problems involving scalar and vector hysteresis, based on minimal material measurement data. To be able to ensure this convenience, the identification module heavily relies on the benefit of
using the so-called Everett function [2], in connection with the classical Preisach model, for reducing the strong ill-posedness of the scalar model identification. The vector model is identified based on only two or more scalar data sets on directions inside the rolling-transverse directions plane. The necessary user input data are: the point-by-point H-B description of the initial magnetization curve, and of the upward major branch, for each of the rolling/transverse directions (figure 1).

The identification process employed consists in two stages:
- scalar identification: a scalar Preisach model is constructed for each of the two magnetization directions described by the user through the inputted raw data. The description of hysteresis using the Everett function is a variant of the Preisach approach. Instead of trying to reconstruct the Preisach distribution function itself, one is reconstructing for every node of the Preisach triangle the integral of the Preisach distribution, obtaining the so-called Everett distribution [2]. The identification approach based on the Everett distribution is probably the only alternative when the experimental information is scarce;
- vector identification: after Preisach identification for each initial direction, the vector model is obtained as a superposition of scalar models continuously distributed along all angular directions. The identification approach is based on the proposal (by Ragusa and Repetto[3,4]), whereby the Fourier coefficients for the 2D Preisach distributions are solved on a special mesh in the Preisach triangle.

Scalar identification

Everett function represents the integral of the Preisach weights over the minor triangle (Fig. 2):

\[ E(\rho) = \int\int \mu(\alpha, \beta) d\alpha d\beta \]  

(1)

Figure 1: Example of raw magnetization data provided by the user as H-B pairs for each main axis (rolling, transverse).
The identification process requires regular-grid samples. Thus, the raw samples must be interpolated and transferred to a uniform sampling grid. Moreover, it is required the calculation of a common level of H (at saturation) to be used for the scaling of the Preisach triangles for the two directions (rolling, transverse). Thus, the uniformly sampled data are extended for rolling and transverse direction in order to have the same H at saturation.

The scalar identification process consists in computing the Everett distribution in the nodes of the Preisach triangle for each magnetization direction, rolling and transverse (figure 3).

The Everett distribution is known only for the following sets (see figure 3):
- the nodes corresponding to the first magnetization curve (the nodes on line OR);
- the nodes corresponding to the major loop (the nodes on lines PR, QR);
- the nodes on the main diagonal – it is assumed that the Everett distribution does not account for any reversible effect, so all Everett values on this segment are taken zero (the nodes on line PQ).

Thus, in figure 3, only for the nodes marked in red, one knows a-priori the Everett value. Because the Everett distribution is symmetric with respect to the 2nd diagonal OR, the task of the scalar identification procedure is to find the Everett distribution for the interior nodes (black) belonging to the superior triangle (blue).

The Everett values on main segments O→R and Q→R (identical to P→R) are computed from the input data set. After these a-priori known values are inserted in Everett matrix, the rest of the matrix must be filled using an original quasi-regularized. The Everett values in the internal nodes are filled row-by-row, employing a similarity rule. The algorithm permanently checks if the values on the newly calculated row are all greater than the already known values from the diagonal OR. When a violation occurs, the current value is corrected and the similarity calculation restarts from that column.
3 Numerical results

Figure 4 shows the VSM measurements data for a metro card specimen for various angles, provided by UPB team.

Figure 5 shows the first order branches obtained based on the identified Everett distributions starting from the experimental data, for the rolling axis and the transverse axis.

Figure 6 shows the demagnetization curves obtained based on the identified Everett distributions starting from the experimental data, for the rolling axis and the transverse axis.
Conclusions

The paper presented a numerical method based on Classical Preisach model for the characterization and modelling of magnetic materials with scalar and vector hysteresis, starting from a minimal material measurement data.

References


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