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Characterization of static hysteresis models using first-order reversal curves diagram method

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Abstract

First-Order Reversal Curves (FORC) diagram method is known as a non-parametrical identification method for the Classical Preisach Model. However, the FORC diagram is used for material characterization and can be simulated by any hysteresis model. In this paper we analyze the possibility to use FORC diagrams for the identification of the hysteresis models parameters and the limits of this approach.
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Keywords: Preisach-type models; First-order reversal curves; Energetic model; Jiles–Atherton model

1. Introduction

A significant number of models for the simulation of hysteretic processes have been developed and are used in various concrete situations. Whereas any of these models can be used to fit a simple magnetization process, like the Major Hysteresis Loop (MHL—the zero-order magnetization process), it is not always clear what the criterion is for the use of a certain model in a given case and how accurately can that model describe higher-order magnetization processes. After selecting a model, the central problem is the identification of the optimum values of the parameters for a given sample. Unfortunately, in many papers we see identifications made based on a more or less arbitrary selection of experimental data. In Fig. 1a, we present identical MHLs calculated with the Classical Preisach Model (CPM [1–3]) for two different sets of parameters (Fig. 1b shows the Preisach distributions). Mayergoyz has shown that, for a complete identification of a CPM, a set of First-Order Reversal Curves (FORC) should be used [3]. The sample magnetic moment on a FORC is a function of the actual applied field, H, and of the reversal field, H_r, on the descending branch of MHL, $m^-_{\mathrm{FORC}}(H, H_r)$. As shown in Fig. 2, the FORC distribution is calculated as the second-order mixed derivative of the moment measured on the FORC:

$$\rho(H, H_r) = -\frac{1}{2}\frac{\partial^2 m^-_{\mathrm{FORC}}(H, H_r)}{\partial H \partial H_r}, \tag{1}$$

which is identical in CPM with the Preisach distribution. This type of Preisach distribution identification is non-parametrical, as we do not impose that the distribution have any particular analytical shape. Hence, the accuracy of the distribution identification is dependent on the field-step size in the experiment. Pike et al. [4] have extended the use of FORCs as an experimental tool to observe the characteristics of any magnetic material with hysteresis. The FORC diagram (or contour plot of the FORC distribution) method is important because it relies on experimental data. FORC diagrams have already been reported for various types of magnetic materials (hard magnetic, soft magnetic, recording media, magnetic rocks, particulate media, etc.) [5]. The method has been extended to other types of hysteresis, as well [6–8]. In this paper, we discuss the possible use of the FORC diagram method as an identification tool for any type of hysteresis model and the limits of this approach.

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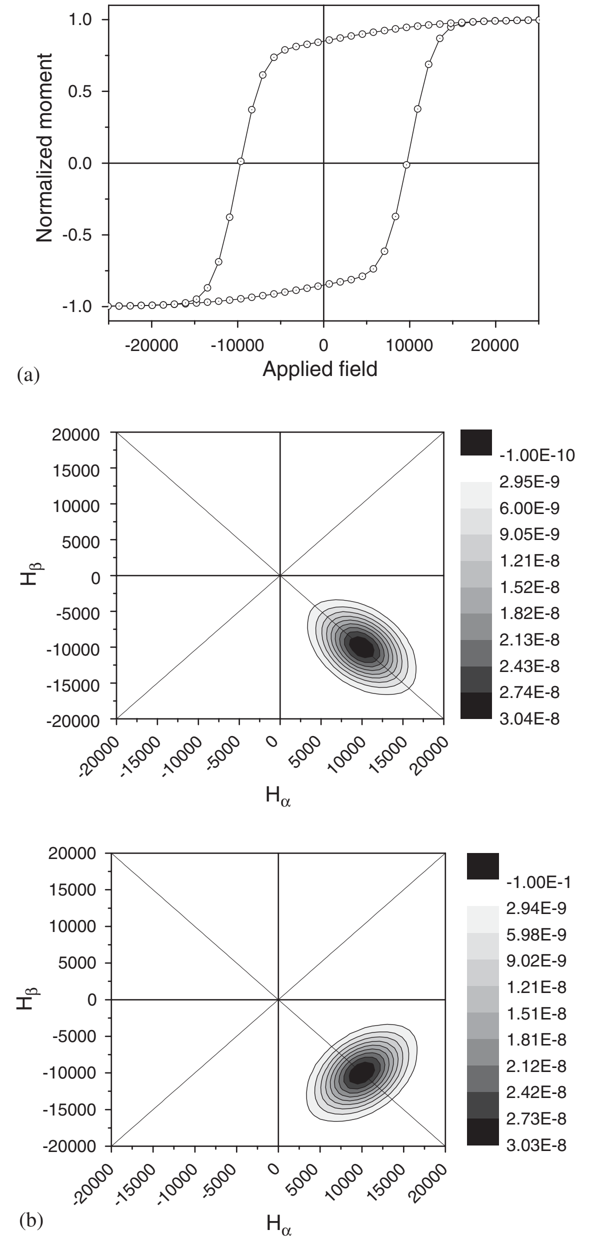

Fig. 1. (a) Identical Major Hysteresis Loops calculated with Classical Preisach Model for two sets of parameters (model's parameters defined as in Ref. [12]). All the distributions (of coercive, interaction fields and of the reversible part) were considered to be Gaussian. (b) The Preisach distributions for the two sets of parameters given in Fig. 1a.

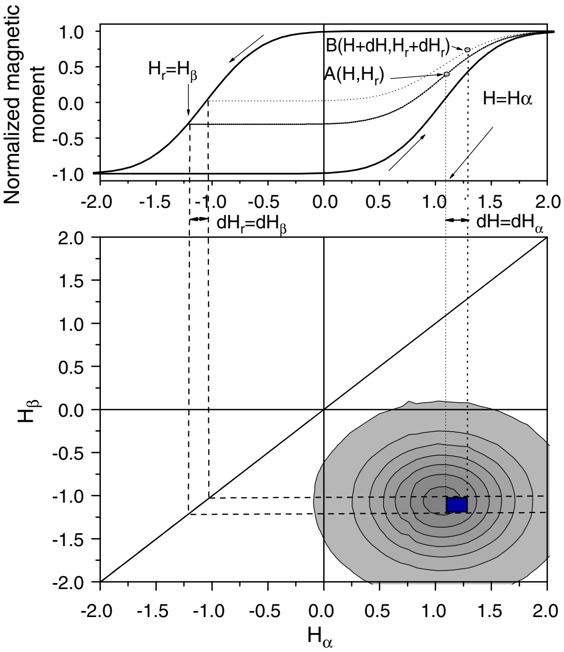

Fig. 2. FORC curves and diagram.

2. FORC diagrams generated by hysteresis models

Since the zero-order magnetization curve (the MHL) is obviously not sufficient to identify the parameters of a hysteresis model, we can use FORCs to find the optimum set of parameters for any particular model. The use of the FORC diagram is recommended in order to better observe the differences between the experimental and the simulated FORCs.

Figs. 3 and 4 present typical FORC diagrams obtained with the Jiles–Atherton (JA) model [9] (Fig. 3) and the energetic (Hauser) model [10] (Fig. 4), both of which have been implemented, as described in the references provided. What we have observed is that both these models have quite a limited set of FORC diagram shapes that can be simulated and which correspond to/indicate the range of materials that can be modeled by each of the two models. As expected, the JA model describes the typical features of soft magnetic materials and the energetic model seems to describe well strongly interacting systems, like magnetic nanowire systems. Meanwhile, the classical Preisach model, which is conceptually closer to the non-parametrical FORC diagram identification method, can reproduce exactly any diagram, provided that the experimental distribution is used in the model. Is this fact enough to guarantee that a hysteresis model can accurately describe high-order magnetization curves? Unfortunately, even in this case, proving that a system satisfies the respective necessary and sufficient conditions, requires the execution of a systematic experimental study, which involves a huge number of experiments, which are often not conclusive, due to the inherent experimental errors. For all the other hysteresis models, the conditions that can assure that these models will correctly describe curves of any order, for a certain sample, are not defined. Consequently, the good fit of the FORC diagram will not be a sufficient condition to assure the accurate simulation of higher-order curves. The fit of the FORC diagram could be seen only as a necessary condition for any hysteresis model. If this condition it is not satisfied, we cannot expect that the model will describe higher-order curves correctly. Given that the MHL and the FORC diagram can be represented with sufficient accuracy by more than one phenomenological model and that there