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Physica B 372 (2006) 128–132
PHYSICA B
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Fast computing vector hysteresis model

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Abstract

Vector hysteresis modeling is necessary in order to describe many magnetic processes ranging from magnetic recording to electrical machines. Several models have been proposed to describe vector hysteresis behavior but this is an open research topic so far. This paper introduces a simplified vector model based on the Preisach approach that intrinsically satisfies loss and saturation properties. It is able to reproduce isotropic and non-isotropic behavior. The second one when in the experimental rotational loops the vector magnetization is delayed with respect to the rotational field for each angle. The magnetization is computed in two independent steps, amplitude and phase. The proposed formulation allows fast computation of rotational and alternative vector magnetization, the computational time is of the same order of the Scalar Preisach Model. In this paper, we underline the amplitude dependence of computational time because it is the bigger contribution to the total computation of the magnetization.
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PACS: 77.80.Dj; 75.90.+W

Keywords: Preisach model; Vector hysteresis

1. Introduction

In order to study many magnetic applications, ranging from magnetic recording to electrical machines, it is necessary to use vector hysteresis models [1–9]. This approach is required because the applied vector magnetic field and the vector magnetization are not parallel. Physical behavior observed in real magnetic materials excited by vector field deals with saturation and loss properties. The first one refers to the requirement that magnetization must not exceed saturation and that for large fields it can actually achieve saturation. Loss property refers to the fact that as size of a rotating-field increases, the magnetic losses first increase and then decrease to zero [1]. Presently, modeling of vector hysteretic behavior of magnetic materials is an open research topic, and several models have been recently proposed for its description. Mayergoyz [2] has introduced a vector model that uses the Scalar Preisach Model (SPM) with different distribution functions for each direction $P(U,V,\alpha)$, where α is the angle between the vector applied field and the x-axis. This model is attractive for its mathematical properties, but it is rather complex from the computational point of view. Furthermore, it satisfies the saturation property but not the loss one. Experimental vector measurements have shown that when a material is magnetized in one direction, it becomes demagnetized in the perpendicular one [4]. Starting by this experimental remark, Della Torre introduced a model (Simplified Vector Preisach Model) that uses only as many Preisach models as there are dimensions in the problem, placed along the principal axes of magnetization. The hysterons for the different Preisach functions are coupled by suitable selection rules, in order to satisfy the saturation property a rotational correction is required [1,5]. These kind of models, where the hysterons are coupled are called "coupled hysterons model" [1]. The model introduced in this paper fits on this category of vector Preisach models. The magnetization is computed in two independent steps: the first one determines its amplitude; the second computes the angle between vector magnetization and vector-applied field. This model in 2D is defined by means of the following

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doi:10.1016/j.physb.2005.10.032

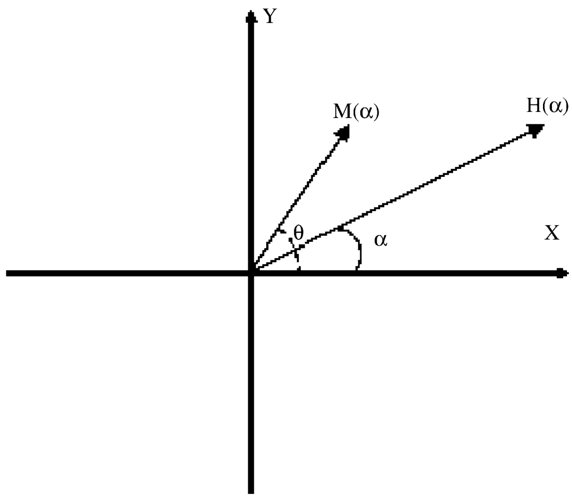

Fig. 1. Applied field and magnetization for fixed α and t.

terms: two independent Preisach functions computed in the principal axes of the system ($P_x(U_x,V_x)$ and $P_y(U_y,V_y)$), a weight function $G(\alpha)$, a phase diagram L_φ (α, $|H|$) (α is the angle between vector-applied field and x-axis, $\varphi = (\theta - \alpha)$ see Fig. 1), and a function $T_{\Delta\alpha}$ that takes into account the history of the angle between vector magnetization and applied field. This model intrinsically satisfies both saturation and losses properties. The identification of function $T_{\Delta\alpha}$ is non-trivial and the knowledge of alternative and rotational loops is not enough to solve it. In this paper, we point out the features of the model in order to describe experimental rotational and alternative loops only; in this case the knowledge of the $T_{\Delta\alpha}$ is not necessary. This is a good assumption when the measurements are based on a control system that adapts the applied field in order to obtain the loops [6–9]. The complete identification procedure will be discuss elsewhere. Although it is a complex feature, the main advantage of the model is the computational time that is practically the same of the amplitude computation.

2. Theory

The identification procedure has to determine all of the parameters of the model by means of the experimental data. This model needs alternate and rotational loops. The alternate permit to determine $P_x(U_x,V_x)$, $P_y(U_y,V_y)$), and $G(\alpha)$, whilst L_φ (α, $|H|$) is computed by means of the rotational loops. A key point of a simple identification procedure described below is to postulate that measured vector magnetization is oriented in the same direction of vector-applied field when the starting magnetic state is the demagnetizing one and an alternative field is applied along the principal axes of the material. The $P_x(U_x,V_x)$ function can be computed by means of the knowledge of a set of first-order reversal curves [2] symmetric minor loops [3], or major loop [1,3] computed along the x-direction as in scalar hysteresis identification. The $P_y(U_y,V_y)$ can be computed in the same way considering the y-direction. The Preisach function for each other direction is computed by means of the following equation:

$$P_\alpha(U_\alpha, V_\alpha) = (1 - G(\alpha))\, P_x(U_x, V_x) + G(\alpha)\, P_y(U_y, V_y), \quad (1)$$

where α is the direction with respect to the x-direction (with this choice we do not lessens generality). $G(\alpha)$ values are between 0 and 1. It is computed by fitting the experimental alternative data for different direction. By physical reasons, the Preisach function has to satisfy the symmetry property, this means that $G(\alpha)$ satisfies the following:$G(\alpha) = G(-\alpha) = G(\pi - \alpha) = G(\pi + \alpha)$. Fig. 2 displays some possible shapes of the G versus α. For a generic history of the applied-field vector, the magnetization amplitude is computed by evaluating the following double Everett's integral [2]:

$$M(H,\alpha,t) = \int\int_{D(H)^+} P_\alpha(U_\alpha, V_\alpha)\,\mathrm{d}U_\alpha\,\mathrm{d}V_\alpha - \int\int_{D(H)^-} P_\alpha(U_\alpha, V_\alpha)\,\mathrm{d}U_\alpha\,\mathrm{d}V_\alpha, \quad (2)$$

where $M(H,\alpha,t)$ and $H(\alpha,t)$ are the input and the output of the model at the time t. $D(H)^+$ and $D(H)^-$ are the positive and negative domain of Preisach triangle where the hysterons give a positive or a negative contribution to the total magnetization [1,2]. The maximum value of the magnetization predicted by (1) can achieve its saturation magnetization M_S. When the magnetic material behavior is the same for each direction (isotropic behavior), P_x and P_y are the same, and the weight function has not to be determined.

The phase diagram can be computed by means of the knowledge of the experimental rotational loops. The angle between the vector magnetization and applied field for a given magnetic material depends on the magnitude of the applied field. Considering rotational low-frequency measurements (in the range of validity of the static scalar

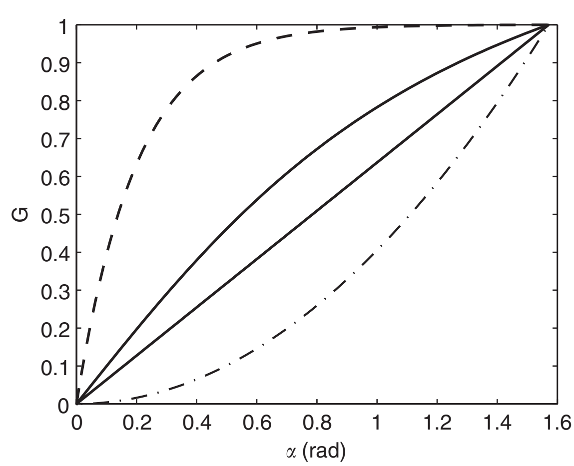

Fig. 2. Examples of possible shape of the G(α), with $0<\alpha<\pi/2$.

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