Journal of Optoelectronics and Advanced materials Vol. 4, No. 2, June 2002, p. 293 - 296

MICROMAGNETIC INVESTIGATION OF INTERACTIONS IN VECTOR HYSTERESIS MODELS

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A complex analysis of magnetostatic interactions in particulate media is performed by means of a micromagnetic model. In the case of structured 2D media, the properties of the interaction field distribution are presented. The vector properties of the interaction field distribution are also analysed. The hypothesis concerning interactions in the scalar Preisach-type models are validated while the same hypothesis used in the vector Preisach models are not entirely in agreement with the physical reality in particulate media.

(Received February 21, 2002; accepted May 15, 2002)

Keywords: Micromagnetism, Hysteresis modeling, Vector models

1. Introduction

An important physical factor that should be carefully analysed in modern high-density recording magnetic materials is the inter-particle interactions. Due to the technological requirements, in a modern recording medium the ferromagnetic particles should have smaller volumes and the packing ratio should be increased.

The Preisach-type models are best suited for describing the magnetisation processes of interacting particulate media. Statistical and mean field interactions are considered in the "moving" Preisach models [1,2]. While the statistical interactions are characterized by the Preisach distribution, the mean field interaction is taken into account as a shift of the distribution as a function of the total magnetic moment of the sample and usually is associated with exchange interactions.

Since the Preisach model is usually seen as a phenomenological model, in order to clarify the profound physical grounds of the hypothesis of the Preisach model, a physical model has to be used. In this paper this analysis is performed using a micromagnetic model.

2. The model

We used a system of interacting spherical single domain particles that have the magnetic moment $\vec{M}$ movement governed by Landau-Lifshitz-Gilbert (LLG) differential equation [3]:

$$\frac{d\vec{M}}{dt} = -|\gamma|\left(\vec{M}\times\vec{H}\right)+\frac{\alpha}{|\vec{M}|}\left[\vec{M}\times\left(\frac{d\vec{M}}{dt}\right)\right] \tag{1}$$

Each particle has dipole interactions with its neighbours. The particles, randomly dispersed in a parallelepiped, have Gauss distribution for easy axis orientation and anisotropy field and a lognormal volume distribution. To avoid the inconveniences introduced in the interpretation of the results by the presence of the demagnetising field, a free boundary condition was considered.

After computing the total field acting on each particle – as the vector sum of external magnetic field and the interaction field – a system of $2\cdot N_{part}$ differential equations is solved (N_{part} – the total number of particles). The simulations are made on few thousands particles systems.

3. Statistical and mean interaction fields

The first objective of the analysis was to test the hypothesis concerning the interactions in the Preisach-type models. As we mentioned before, in the moving versions of the Preisach models, the interaction fields are described by two terms: a statistical interaction field and a mean interaction field. The physical ground of this assumption is that the interaction fields are distributed. This distribution is usually considered Gaussian in Preisach modelling:

- in the Classical Preisach model the most probable value of the interaction field is zero
- in the Moving Preisach models the peak position has a shift proportional to the total magnetic moment of the sample while the standard deviation remains unchanged
- in the Variable variance Preisach models the standard deviation value depends on the magnetic moment of the sample, as well.

In our simulations made on samples with 3D free boundary conditions, the moving effect is not observed. When the width of the samples is finite the observed shift is a function of the sample width. In figure 1 one may see the interaction field distribution in two different states ($M \cong 0$ and $M = M_{sat}$). A clear shift of the distribution can be seen for the saturated state, but one may also observe a slight asymmetry. The interaction field distribution for the same sample in a demagnetised state is symmetric and has a standard deviation significantly larger than that calculated for the near saturation state.

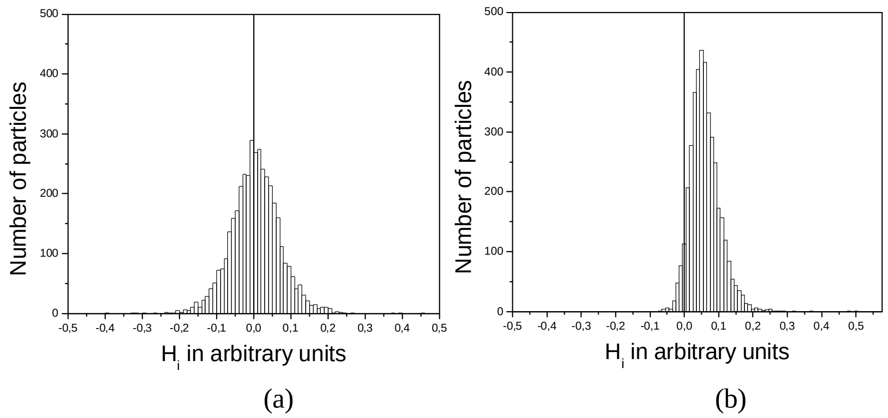


Fig. 1. Interaction field distribution: (a) – sample in the DC demagnetised state, (b) – sample in the positive saturation state.

If the width of the sample decreases the mean interaction field increases. The maximum is attained for a 2D sample, in which all the particles centres lays on an infinite plane

4. Vector interaction field properties

One of the main benefits of the Scalar Preisach-type model is its graphical interpretation of the magnetisation processes. By arranging all system particles in a plane and taking as coordinates their switching fields H_α and H_β one can represent the external field as a straight-line separating this plane in two regions: the region of the switched particles and the region of the particles which are not yet switched (the magnetic memory region).

Charap [4] made a generalization of the graphical representation for Vector Preisach-type models by replacing the field straight line with a curved line resulting from the Stoner-Wohlfarth algorithm of calculus of the critical switching fields and given by the equation:

$$\left(H_{x'} + H_i\right)^{\frac{2}{3}} + H_{y'}^{\frac{2}{3}} = H_c^{\frac{2}{3}}$$

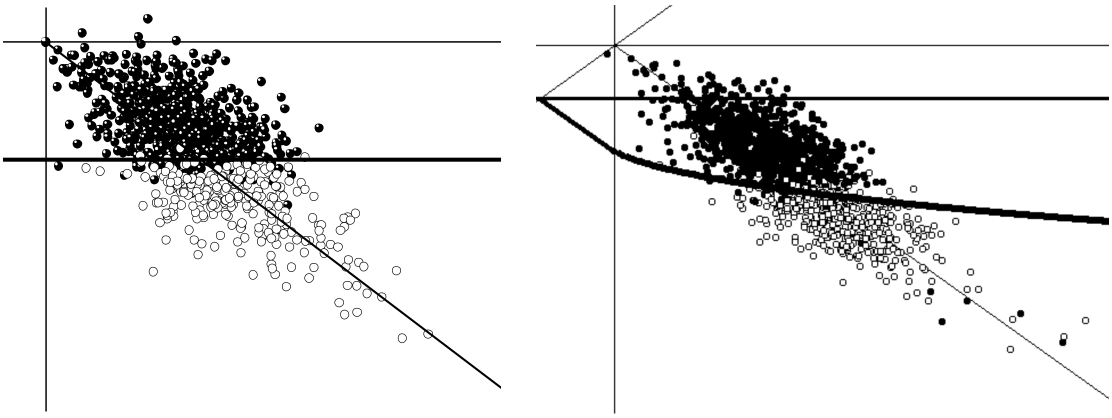
where $H_{x'}$ and $H_{y'}$ are the projections of the external field on the easy and hard axes,

$$H_i = -\frac{H_\alpha + H_\beta}{2} \text{ and } H_c = \frac{H_\alpha - H_\beta}{2}.$$

We have presented an algorithm for the Preisach plane made over by an LLG ensemble of particles [7-8] and we have shown that the graphical representation for the scalar case is verified with a high degree of accuracy by the physical model (Fig. 2(a)). Using the same algorithm for the case when the external field makes an angle with the system easy axis direction we obtained a very good verification of the vector Preisach-type representation (Fig. 2(b)).

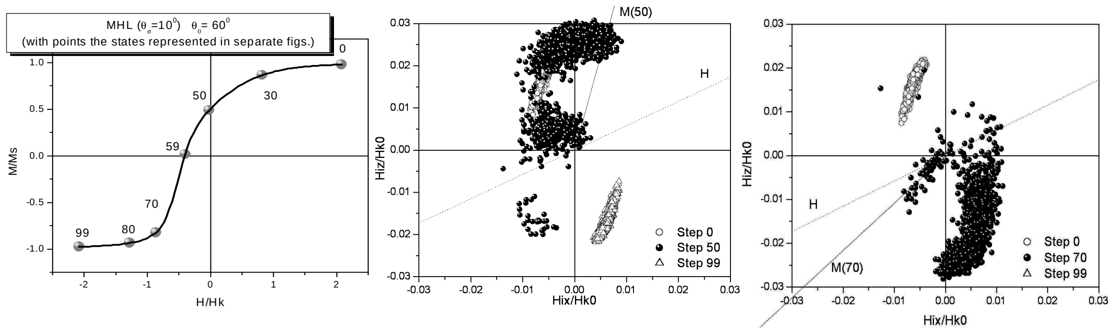
The hypotheses used in the scalar versions of the Preisach model are usually extrapolated for the case of the Vector Preisach models [4-6]. The most customary assumption is that the statistical interaction fields are all oriented on a single direction (field direction) and the vector mean field term direction is on the sample total magnetic moment direction. A linear relation between the mean interaction field and the sample total magnetic moment is also presumed.

We have tested these hypotheses on the 2D sample, for which we know that a significant moving term exists. In Figs. 3(b) and 3(c) are shown the vector interaction fields evolution on the major hysteresis loop for a 60° angle between the external field direction and the sample easy axis. In Fig. 4 the shift of the peak interaction field distributions for three projection directions (easy axis, hard axis and field direction) is presented.



(a) (b)

Fig. 2. Scalar (a) and vector (b) Preisach plane verification for a magnetic state on the upper MHL branch. Black – particles in negative state, hollow – particles in positive state.



(a) (b) (c)

Fig. 3. Major hysteresis loop for a 60^0 angle between the field and the system easy axis (a) and in-plane evolution of interaction field vector tips for two MHL points (50, and 70 – see (a)).

It is interesting to observe that the shift is not any more linearly dependent on the sample magnetic moment projection on the field direction. However, the shift of the interaction field projections distribution on the easy axis and perpendicular to the sample easy direction is linear with a high degree of precision. On these directions the proportionality constants are different. In Vector

Preisach modelling the existence of two moving parameters [4] (parallel and perpendicular to the sample easy direction) is a common presumption that is confirmed by our simulations. When the easy axes are assumed to be randomly distributed in the plane, the two moving parameters are equal.

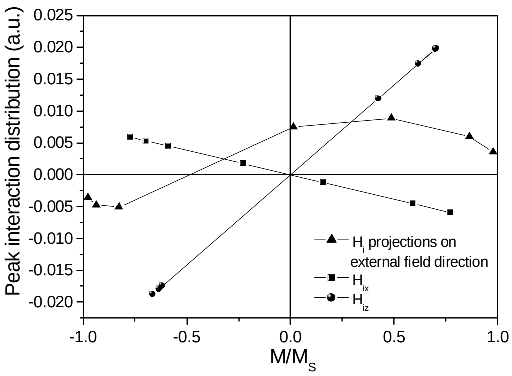


Fig. 4. Linear moving effect on easy axis (Oz) and hard axis (Ox) and non-linear moving effect on external field direction.

5. Conclusions

In this paper we have studied a system of single-domain ferromagnetic particles interacting only with magnetostatic dipolar fields. A number of conclusions can be extracted from the analysis presented in this paper.

When the magnetic moment of the sample is measured on the same direction with the applied magnetic field, the interaction field projection on this direction is following exactly the rules that are specific to the scalar Preisach-type models. The effects described by the linear moving Preisach model and variable variance model were obtained in the micromagnetic simulations for some particulate media. In the 3D sample, only statistical interactions are present. In the 2D sample the moving term is significant.

The classical graphical interpretation of the magnetisation processes in the Preisach model and Charap vector generalisation of this representation are confirmed.

The analysis made on the vector properties of the interaction field distribution shows that these fields have an orientation distribution that depends on the magnetic state of the sample. The shift of the interaction field projections on the direction parallel and perpendicular to the sample easy axis depends linearly on the magnetic moment projection on these directions. On any other direction non-linear shift is observed.

These results are adding physical insight to the problem of interactions in scalar and vector phenomenological Preisach models.

References

[1] E. Della Torre, J. Appl. Phys. **36**, 518 (1965).
[2] V. Basso, G. Bertotti, IEEE Trans. Magn. **30**, 64 (1994).
[3] P. R. Gillete, K. Oshima, J. Appl. Phys. **29**, 3315 (1958).
[4] S. Charap, A. Ktena, J. Appl. Phys. **73**, 1073 (1993).
[5] F. Ossart, R. Davidson, S. H. Charap, IEEE Trans. Magn. **31**, 4260 (1995).
[6] R. J. Davidson, S. H. Charap, IEEE Trans. Magn. **32**, 4198 (1996).
[7] Al. Stancu, L. Stoleriu, M. Cerchez, J. Appl. Phys. **89**, 7260 (2001).
[8] Al. Stancu, L. Stoleriu, M. Cerchez, J. Magn. Magn. Mater. **225**, 411 (2001).