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Influence of statistical interactions on the ΔH method

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This paper is dedicated to a complex study of the effect of the statistical field interactions on the ΔH method used as a tool for experimental evaluation of the intrinsic field distribution in particulate media, especially in modern perpendicular recording media. A Preisach-type approach is considered, in the first level of complexity we consider a Classical Preisach model (CPM) in which unvariable interaction field distribution is taken into account and a more general approach given by the PM2 model (Preisach Model for Patterned Media) is presented. PM2 model was developed as a special tool for characterization of interactions in structured materials like the well known patterned media. In such systems, the interaction field distribution has a complex structure and show a strong dependence on the sample magnetization. For each model we have compared the results for a system with negligible interactions with the more interactive systems.

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1. Introduction

The ΔH method [1] is currently used as a method for experimental evaluation of the intrinsic field distribution in particulate media, especially in modern perpendicular recording media [2-5]. The particulate magnetic media properties are strongly influenced by the interactions in the medium. The authors take into account the interactions in terms of a mean field effect. However, statistical interactions were also proven to play an important role in the magnetization processes and they cannot be ignored due to their influence in media noise and also to their determinant behavior on the hysteretic properties.

In this paper we present a Preisach analysis of the influence of the particles statistical interaction on the standard deviation of the intrinsic switching field distribution and on the ΔH method. These interactions were not taken into account so far, and previous analyses have shown that the mean-field approximation is satisfactory only near the saturation, which is not the case in the experiment (the measurement is made at half the saturation).

2. The ΔH method

The intrinsic switching field distribution $D(H_S)$ of the magnetic recording media may be obtained from the difference (noted with ΔH) between the field position at which the magnetization reaches half of the saturation magnetization on the major loop (H_M) and on a remagnetisation curve that starts in the coercivity point (H_m) (see Fig. 1). Neglecting the influence of the particles interactions and considering that $D(H_S)$ has a Gaussian shape, ΔH is the difference between 25% and 75% of this distribution [1].

In [2] the method is generalized in order to not restrict the measurement only to the reversal curve that starts at the negative coercivity. Using any first-order reversal curve characterized by the moment M_{rev} in the reversal point, the method is named $\Delta H(M,\Delta M)$ where $\Delta M = M_s - M_{rev}$, with M_s the saturation moment of the sample. The authors also improve the theory on which the method is based, taking into account a mean-field interaction approximation. For a Gaussian shape of intrinsic switching field distribution $\Delta H(M,\Delta M)$ is given by:

$$\Delta H(M,\Delta M) = \sqrt{2}\sigma_c\left(erf^{-1}\left[M+\Delta M\right] - erf^{-1}\left[\Delta M\right]\right) \quad (1)$$

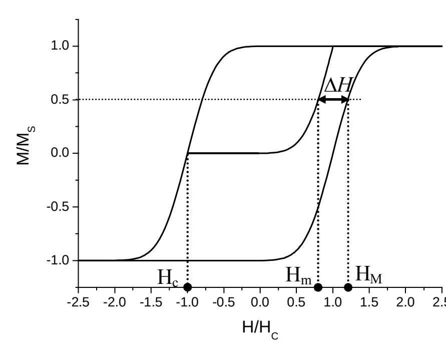

Fig. 1. Determination of width $\Delta H = H_M - H_m$ between remagnetization and major loops curves at the value of M equal to half of saturation magnetization M_S. H_c is the coercive field.

However, both these analyses do not tackle completely the problem of interactions. We have used the Preisach model which is the only phenomenological model that describes adequately the statistical interactions. In the “moving” variant of the model [6] both statistical and mean-field interactions can be considered properly. To improve further the accuracy of the description of interactions (including the fact that the variance of the interactions field distribution is state dependent [7] and finally that in perpendicular media one may expect a state dependent bimodal interaction field distribution) we have used a Preisach-type model, developed by us recently, namely the Preisach Model for Patterned Media (PMPM = PM2 model [8]).

3. The CPM model

In most implementations of the CPM the Preisach distribution is a product of two statistically independent distributions, one of coercivity and one of interaction fields (referred to as statistical interactions). Usually, both distributions are considered to be of Gauss-type which allows a further simplification of the expressions of the main magnetization curves using the well known mathematical functions error function *erf* and complementary error function *erfc*. In this case the magnetic moment on the increasing branch of the major hysteresis loop can be estimated from:

$$m^{+} = -1 + 2e(H_{\max}, H) \tag{2}$$

The first-order reversal curve (FORC) starting at coercive field ($-H_c$) can be calculated using:

$$m^{-}_{FORC} = 1 - 2e(H_{\max}, -H_c) + 2e(H, -H_c) \tag{3}$$

where $e(H_{\max}, H)$ is the Everett integral, $H_{\max}$ is the maximum value of the applied field. To calculate $\Delta H = H_M - H_m$ one solve the system:

$$\begin{cases} m^{+}(H_M) = m_s / 2 \\ m^{-}_{FORC}(H_m) = m_s / 2 \end{cases} \tag{4}$$

In Fig. 2 one may see the dependence of the difference ΔH calculated with CPM as a function of standard deviation σ_c of the intrinsic switching field distribution for three values of the standard deviation σ_i of the statistical interaction distribution. These dependences are compared with the variation of ΔH in the non-interactional cases presented in [1] and when interactions are described by the mean field interaction term - equation (1). In both cases one may observe a rather linear dependence in this range but different slopes are obtained when the statistical interactions are tacked into account.

4. The PM2 model

Micromagnetic simulations makes on particulate media shows that the interaction field distribution (IFD) is state dependent. In many cases the IFD average value is proportional to the magnetic moment of the sample and the IFD variance is decreasing with the total moment. The first effect is included in the moving Preisach model which essentially includes a supplementary mean-field term in the CPM [6]. The second is taken into account in the Variable Variance Preisach model [7].

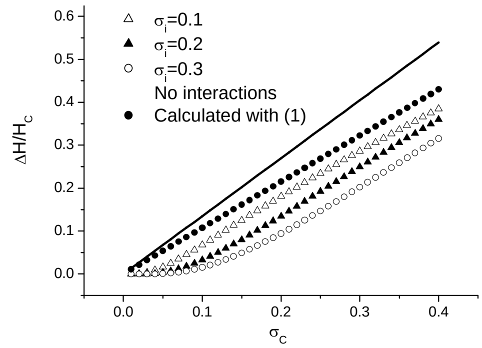

Fig. 2. ΔH vs standard deviation σ_c of intrinsic switching field distribution and as a function of standard deviation σ_i of statistical interaction distribution.

Micromagnetic simulations made on strongly interacting particulate media and on structured particulate media have shown that IFD can have even a more complicated behaviour as a function of the magnetic state of the sample. Bimodal and even multi-modal IFD have been reported on such materials [9]. CPM and the modified Preisach models mentioned before (moving and Variable Variance) can not include such IFDs and as a consequence, a new model was necessary – the Preisach Model for Patterned Media (PM2). In PM2 a state dependent bimodal interaction field distribution is taken into account as:

$$p_{ii}(h_i) = \frac{1}{\sqrt{2\pi}\sigma_i}\left\{\frac{1+m}{2}\exp\left[-\frac{(h_i - h_{i0})^2}{2\sigma_i^2}\right] + \frac{1-m}{2}\exp\left[-\frac{(h_i - h_{i0})^2}{2\sigma_i^2}\right]\right\} \tag{5}$$

where m is the normalized magnetic moment of the sample h_i is the standard deviation of each component distribution and h_{i0} is value of the field characterizing the degree of separation between the two peaks of the distribution. The fields notated with small h are measured in a rotated system of reference (with 45°) with respect to the classical Preisach coordinate system (H_{α}, H_{β}) containing the switching fields of the particles. The relation between the fields measured in the two systems is $h = H\sqrt{2}$.

Due to a remarkable property of symmetry generated by the use of IFD (2) simple analytical expressions can be found for the fundamental magnetization curves [8]. For example, the magnetic moment on the increasing branch of the major hysteresis loop can be evaluated from:

$$m^{+}(H)=\frac{1-2e_{i,0}(H_{\max},H)}{1+2e_{i,m}(H_{\max},H)}m_s \qquad (6)$$

in which $e_i(H_\alpha,H_\beta)=e_{i,0}(H_\alpha,H_\beta)+me_{i,m}(H_\alpha,H_\beta)$ is the Everett integral, $H_{\max}$ is the maximum value of the applied field and m_s is the saturation moment of the sample. The remagnetization curve starting at coercive field ($-H_c$) can be calculated using:

$$m_{FORC}^{-}(H)=\frac{1-2e_{i,0}(H_{\max},-H_c)+2e_{i,0}(H,-H_c)}{1+2e_{i,m}(H_{\max},-H_c)-2e_{i,m}(H,-H_c)}m_s \qquad (7)$$

On the Figs. 3 and 4 one present the main results given by the PM2 model applied to the ΔH method. In Fig. 2 one has represented the normalized value of ΔH as a function of the intrinsic dispersion of coercivity σ_c. Essentially, in experiment we determine the value of ΔH and from the model one obtains σ_c. In the Figs. 2 and 3 we have presented the results given by:

i). the model developed in [1] for the non-interacting systems of particles;

ii). the model developed in [2] for a system with mean field interactions;

iii). the PM2 model for three values of a fitting parameter (in Fig. 2 the parameter is the dispersion of the IFD σ_i and in Fig. 3 the parameter is h_{i0} from (2) which controls the mean field interactions in PM2).

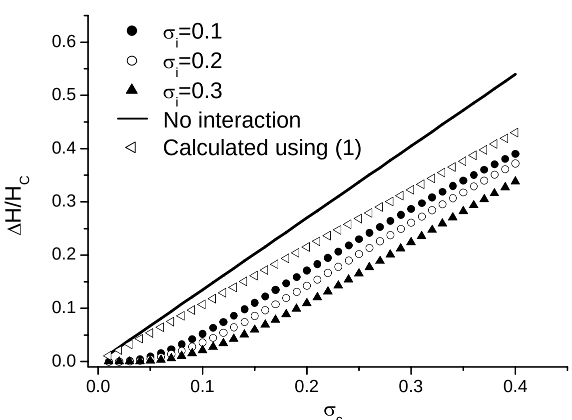

Fig. 3. ΔH vs standard deviation σ_c of intrinsic switching field distribution and as a function of standard deviation σ_i of statistical interaction distribution. h_{i0} from (5) was considered 0.1.

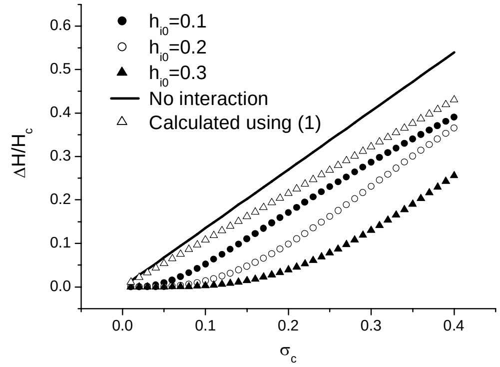

Fig. 4. ΔH vs standard deviation σ_c of intrinsic switching field distribution for three values of the field separation between the two peaks h_i of statistical interaction distribution with a standard deviation $h_i = 0.1$.

Both results show a significant influence of the statistical interactions on the shape of the curve $\Delta H(\sigma_c)$. Especially for systems with a narrow distribution of coercivity the differences can be quite large suggesting that in these cases the use of a more complex model for the interactions, like the one in the PM2 model. As the difference between the results given by i) and ii) models in comparison with iii) remains almost constant for higher coercivity dispersion, the relative error decreases in this case. However, in the entire range of values considerable systematic errors are related in the method with the hypothesis that the statistical errors are negligible. This is in good agreement with the results presented in [10] on the base of FORC analysis.

Our results within the framework of the PM2 model give a straightforward improved method for the interpretation of the results of the ΔH experiment corrected from the main sources of errors. Of course, this will imply a complementary experiment to identify the actual parameters of the PM2 model. The problem of identification in correlation with the ΔH method will be the subject of a further paper.

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References

[1] Tagawa, Y. Nakamura, IEEE Trans. Magn. **27,** 4975 (1991).
[2] Berger et al. IEEE Trans. Magn **41**, 3178 (2005).
[3] E. Yuan, R.H. Victora , IEEE Trans. Magn. **40**, 2452 (2004).

[4] R.J.M. van de Veerdonk et al. IEEE Trans. Magn. **39**, 590 (2003).
[5] R.J.M. van de Veerdonk et al. IEEE Trans. Magn. **38**, 2450 (2002).
[6] E. Della Torre, IEEE Trans. Audio Electroacoust. AE-14, 86 (1966).
[7] M. Pardavi-Horvath et al. IEEE Trans. Magn. **29**, 3793 (1993).
[8] Stancu et al. J. Magn. Magn. Mater **290**, 490 (2005).
[9] R. Tanasa et al. J. Appl. Phys. **95**, 6750 (2004).
[10] M. Winklhofer, G.T. Zimanyi, arXiv:cond-mat/0509074 v1 (3 Sept 2005), paper CC-03 MMM San Jose.

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