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Invited Paper

MAGNETIC CHARACTERISATION OF STRONGLY CORRELATED MAGNETIC PARTICULATE SYSTEMS

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In this paper we present a micromagnetic study of the high density particulate recording media. When increasing the density of magnetic recording media, magnetic clusters may develop in the system. This leads to a different magnetic behaviour of the system as the magnetic moments of the particles are correlated and switch together in potentially large regions inside the medium which act like supper-ferromagnetic domains. We present new hypotheses to explain the observed behaviour and show that this might be considered as a more general case which can be particularised for low interactions systems.

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1. Introduction

In high density particulate recording media, the interaction magnetic fields between magnetic particles in the system may be high enough to create magnetic clusters (i.e. regions of a relatively large number of particles with magnetic moments behaviour correlated due to interactions). In order to study such systems, we simulated ensembles of particles with different distributions of the magnetic and size parameters and assumed coherent rotations as the only switching mechanism and therefore, we considered that the magnetic moment of each particle is driven by the Landau-Lifshitz-Gilbert equation. We used these systems to simulate some of the magnetisation processes, like the major hysteresis loop (MHL). Although the distances between particles are relatively low, we only considered dipole fields of the magnetic moments of the particles, to keep the computations simple. This approximation has been done in the consideration that dipole interactions are long range interactions and also observed that they are high enough to assure the correlation between particles, even though for more accurate simulations, further order terms might be considered. No exchange interactions between particles have been considered in order to study only the effects which might be due to the magnetostatic interactions.

The results of the simulations were fed into the Generalised Preisach model [1] as “experimental data” to perform an identification of the parameters. For the identification we used a procedure we have previously developed and tested [2]. The comparison between micromagnetic calculations and Preisach model results are important as we benefit from the link between micro- and macro- magnetic parameters. We studied the dynamics of the distribution of interactions in the particulate media and tested how accurate the Preisach hypotheses are on different systems. We have shown that, for strongly correlated systems, with only magnetostatic interactions, one may obtain a completely different behaviour of the statistics of the systems, which might lead to a misinterpreting the magnetic characterization parameters.

A mixed (parametric – nonparametric) method for the identification of the Preisach distribution and mean field parameter of particulate recording media was developed in [3].

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2. Micromagnetic system and simulations

We have created particulate systems with different packing fractions and orientations of easy axes, magnetostatic inter-particle interactions, the dynamics of the magnetic moment of particles described by the Landau-Lifshitz-Gilbert equation.

We generated a system of 1400 particles, with uniaxial anisotropies, having the easy axes orientations within an angle of 25 degrees with respect to a preferential orientation. The particles are randomly distributed in a thin layer (3 average diameters thick) with an initial packing fraction of 0.42. Uniaxial anisotropies of particles were considered, with a normal distribution of anisotropy fields having a mean value of 3000 Oe and a standard deviation of 100 Oe. We also considered a normal distribution of particle diameters with a mean value of 20 nm and a standard deviation of 2 nm. Magnetostatic interactions between particles are taken into account. Each particle interacts with a number of neighbors which are determined as the particles which produce a certain minimum field. In-plane periodic boundary-free conditions were used. To create samples with variable packing fractions we expand the system by multiplying the coordinates of each particle by a certain coefficient. We also created systems with different dispersions of the orientation of particles' easy axes for a sample with given positions of the particles. Thus, we created samples which offer the possibility to study the statistical parameters of the system for various packing fractions and degrees of orientation of the easy axes.

We used the systems described above to simulate a number of magnetization processes which are then used in the identification algorithm, as follows: a) the first magnetization, FM_{dc}; the classic FM curve is obtained by ac demagnetizing the sample and then applying progressively increasing dc magnetic fields and measure the magnetic moment of the sample in the presence of the magnetic field; in our case, the magnetization process remains the same, only the initial state is given by the dc demagnetized state of the system, i.e. saturate the sample in one direction and then apply a field in an opposite direction and reduce it to zero to obtain a zero magnetic moment of the sample; b) isothermal remanent magnetization, IRM_{dc}; the classic IRM curve is obtained by ac demagnetizing the sample, apply a magnetic field, remove the field and measure the remanent magnetic moment, for increasing values of the applied field, until the saturation remanence is achieved; as with the FM_{dc} the diference in our curve is that it is started from the dc demagnetized state rather than the ac one; c) the major hysteresis loop, MHL, is measured by saturating the sample in one direction by applying a high enough value of a dc magnetic field, reducing this field to zero and increasing the field to the same saturation value in the opposite direction, and measure the value of the magnetic moment of the sample along this process; d) the dc demagnetization curve, DCD is obtained by saturating the sample in one direction, removing the applied field, applying a field in the opposite direction, removing this field and measuring the magnetic moment for increasing applied fields in the opposite direction.

The parameters identified were compared to the ones obtained by direct calculations from the micromagnetic configuration. We also calculated the interaction field for each particle for all values of the applied field during the MHL process, in order to study the evolution of the interaction field distribution and of the mean field interactions which are due to magnetostatic interactions. During the magnetization processes, we also recorded the value of the interaction field of each particle for each value of the applied field and studied the evolution of the interaction field distribution.

3. Results and discussions

In Fig. 1 we present the micromagnetic and the generalised moving Preisach (GMP) simulations of the FM_{dc}, IRM_{dc}, MHL and DCD curves with the parameters obtained in the identification for a system of particles generated with easy axes orientations within an angle of 25 degrees within the sample plane and a packing fraction of 0.42 [4,5]. The lines represent the corresponding magnetisation processes simulated with the GMP model with the parameters identified using the algorithm.

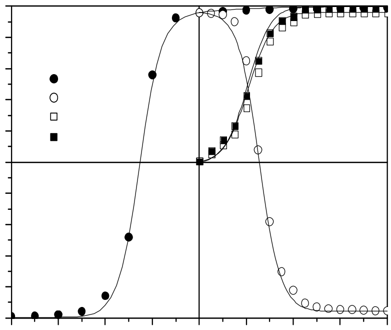


Fig. 1. Simulated, micromagnetic (symbols) and GMP (lines), curves for a system different packing fractions and orientations of the easy axes of the particles in the system.

In Table 1 we present the statistical parameters that describe the system, obtained from the micromagnetic simulations and the ones obtained in the identification for 3 packing fractions of the sample and for the case of random orientations of easy axes of the particles. In Table 1 for the first two samples, there are given the interaction field distribution standard deviation. $H_{\sigma i}$ at magnetic saturation of the sample while for the other two there are given the limits of variation of the standard deviation of the interaction field distribution corresponding to the demagnetized (large value of $H_{\sigma i}$) and the saturated (low values of $H_{\sigma i}$). Table 1 also presents the values of the mean field parameter (α), the mean value (H_{c0}) and the standard deviation ($H_{\sigma c}$) of the coercive field distribution.

Table 1. Micromagnetic and Preisach statistical parameters.

Packing fraction and orientation	Model	α(Oe)	$H_{\sigma i}$(Oe)	$H_{\sigma c}$(Oe)	H_{c0}(Oe)
0.42 PF		1470	445	675	1630
25 deg		210	297	417	1285
0.32 PF		1018	333	590	1667
25 deg		950	822	943	1319
0.28 PF		754	255-1885	625	1628
25 deg		805	760	687	1510
0.42		1470	440-1630	640	1530
random		1330	890	625	1489

One may notice, in all cases, a good agreement between the GMP and micromagnetic simulations but also may observe that the more dispersed system and the system with random orientation of the easy axes are accurately described by the Preisach model, while the parameters for the system with high packing fraction are not in such a good agreement. For the dispersed system and for the one with random orientations of the easy axes of the particles, the interaction field distribution presents a variable variance [6] when simulated with the LLG model and identifying the parameters in a GMP model without variable variance, one still obtains a reasonable fit and an average value of the variance. For the high packing fraction oriented system, the parameters obtained in the LLG model seem to loose their significance. As one may see in Fig. 2, during the magnetization process, the interaction field distribution for the high packing fraction sample changes from a one peak distribution at saturation to a two-peak distribution during the magnetization process, and back to one peak at negative saturation. Obviously this may not be described by a classical symmetrical distribution of interactions and a linear moving term. For this sample, the coercive field distribution also changes due to the changes in the interaction configuration reflecting the vector character of the magnetization processes. This behaviour of the interaction field distribution is explained by the forming of clusters during the magnetization process as one may see in the representation in Fig. 3 where the tones of grey are proportional to the projection of the magnetic moment of the particle on the measurement direction. Clusters of particles switch together in one direction or the other, thus creating a second peak in the interaction field distribution.

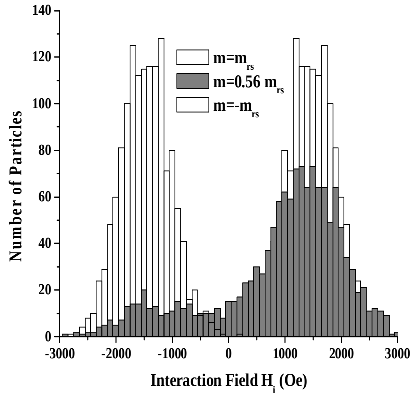


Fig. 2. The interaction field distribution for 3 values of the magnetic moment for a packing fraction of 0.42.

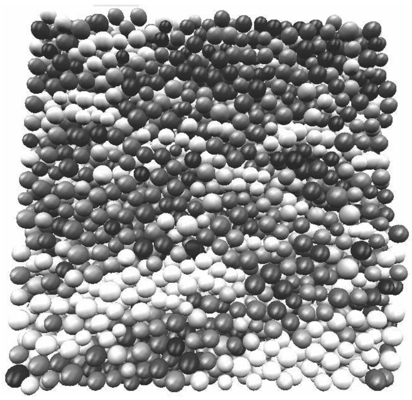
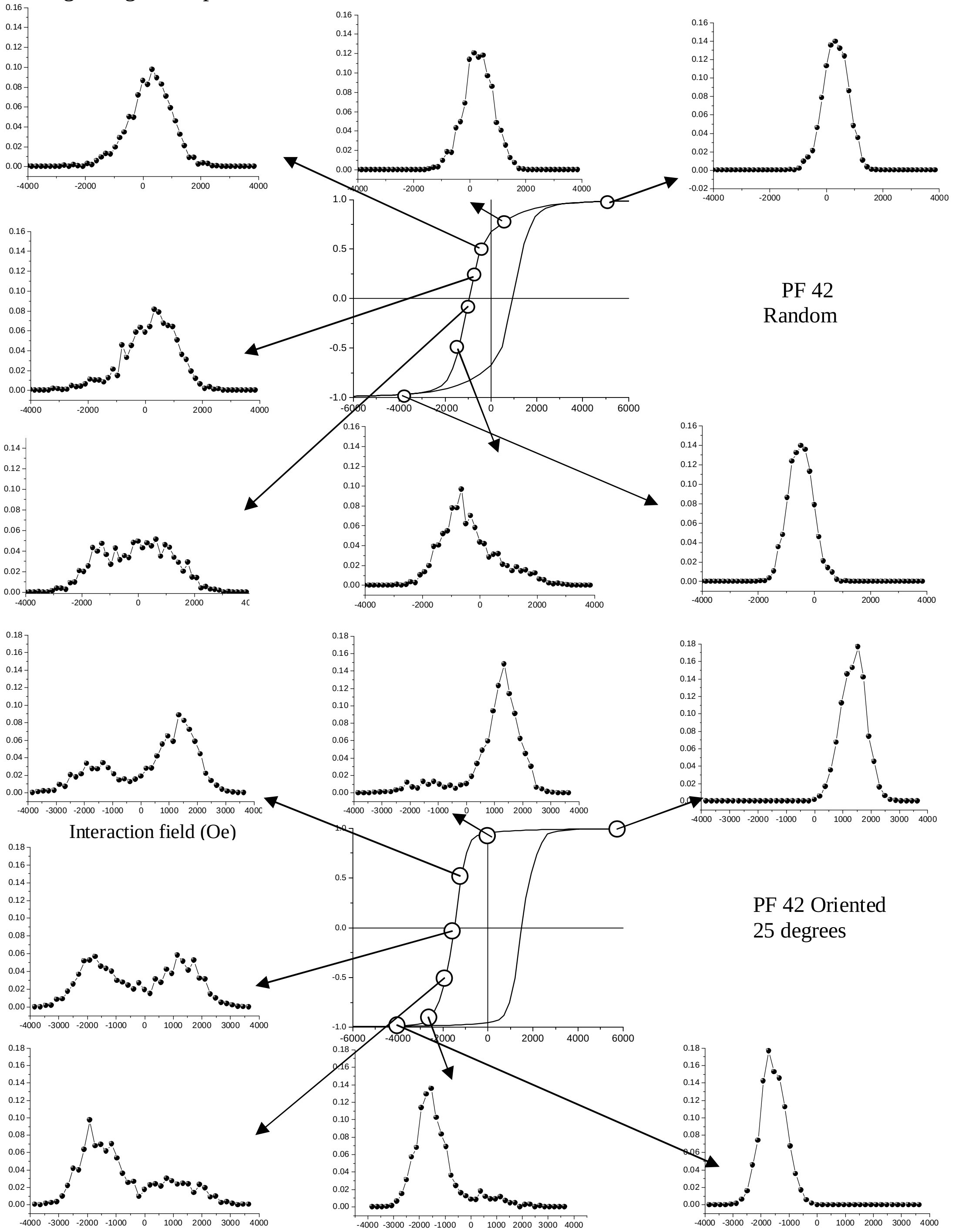


Fig. 3. The system configuration for an intermediary value of the magnetic moment.

As the packing fraction gets higher, the parameters obtained seem to loose their significance. This is because instead of a moving distribution with variable variance, the interaction field distribution changes from a one peak distribution at saturation, to a two-peak distribution and back to one peak at negative saturation. This behaviour is due to the strong interactions which lead to clusters (Fig. 3) that act like separate entities within the particulate system, similar to magnetic domains in bulk materials. If one saturates the system in one direction and an increasing field is applied in the opposite direction, at the beginning one obtains nucleation clusters which become larger as the field increases, like the moving walls of the magnetic domains of a bulk material. Due to this behaviour, one can call these clusters “superferromagnetic domains” in the extended sense of the term used in [7].

In the case of our systems, the magnetic moments of the particles inside the superferromagnetic domain are not perfectly aligned as to provide saturation, but nevertheless, the general behavior is similar. During the magnetization process, the presence of the superferromagnetic domains that switch from one direction to the other, gives rise to practically two peaks in the interaction field distribution. In Fig. 4a and 4b we present the interaction field distribution corresponding to a number of magnetic states of the system during the Magnetic Hysteresis Loop (MHL) process. Fig. 4 a is for the high packing fraction sample (PF=0.42) and oriented easy axes of particles within 25 degrees. Fig. 4 b represents the same states for a equivalent system of the same packing fraction but with random orientations of the easy axes of the particles. In Fig. 4a, one may observe that the shape of the interaction field distribution changes during the MHL process from a one peak distribution to a two peak distribution and respects the symmetry of the MHL process. The weight of the peaks change during the magnetization process but their position remains the same as at the beginning of the process.



a.

Fig. 4. The evolution of the interaction field distribution in different magnetic states of the particulate system in two cases: a n oriented sample (a) and a random oriented sample (b) .

This observation is important because, although one observes a significant mean field contribution, the position of the peaks seems to be not sensible to this. Fig. 4b points out that this effect is almost negligible and that the interaction field distribution acts in the “traditional” moving way. We interpret this behaviour in terms of the contributions of the magnetic clusters in the media which interact with each other rather than individual particles. Thus one obtains a statistical distribution of clusters without a noticeable effect from the mean field distribution. The behaviour is similar to that of the ferromagnetic domains in the sense that, due to large interactions within the cluster, all particles corresponding to one cluster are oriented in the same direction. The behaviour of the border between clusters is similar to the domain wall movement as particles from one cluster switch to the direction of the particles in the neighbouring cluster.

In order to establish the rules which govern this behaviour of high packing oriented particle ensemble we performed an analysis of the change in the area of each of the peaks of the interaction field distribution with respect to the magnetic moment of the sample. The important observation is that the area of each peak varies in a linear manner with magnetic moment of the sample like in Fig. 5.

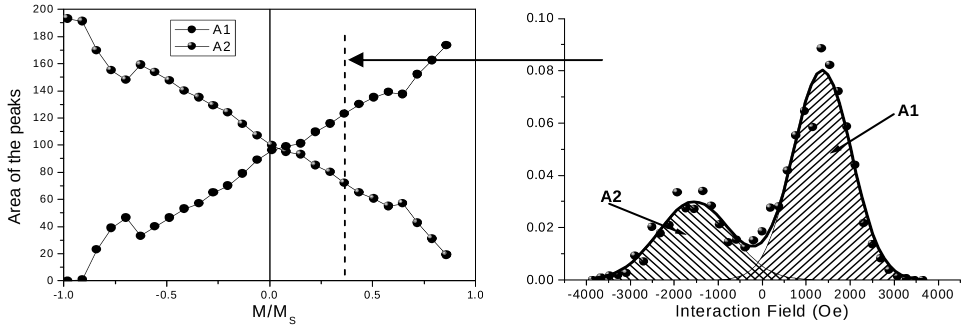


Fig. 5. The dependence of the area of the peaks of the interaction field distribution on the magnetic moment of the sample.

This leads to an interesting possibility of developing a Preisach model with a two peaks distribution and a new interpretation of the "linear moving", this time as the dependence of the area of the peaks against the magnetic moment.

4. Conclusion

There was studied a magnetic particulate system with high packing and good orientation of the easy axes of the particles, yielding strong magnetic interactions, both statistical and mean field. We observed the forming of magnetic clusters and a "domain" – like behaviour of the clusters. We established a new rule of behaviour for this kind of systems and a new understanding of the "moving" for a new type of Preisach model.

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