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CHAIN-OF-SPHERES APPROXIMATION IN MICROMAGNETIC MODELLING OF MAGNETIC RECORDING MEDIA

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The behavior of prolate spheroidal particles, corresponding to the acicular particles found in magnetic recording media is analyzed. Both experimental and theoretical investigations have been carried out to understand and optimize magnetic materials. A problem is the magnetization reversal mode for even the simplest system, a particle small enough consisting in a single magnetic domain.

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1. Introduction

The hysteretic behavior of magnetic material still remains a complicated problem, whose computation often relies on phenomenological concepts. To describe incoherent magnetization reversal in an elongated particle we have used the chain of spheres model (Fig. 1). Jacobs and Bean [1] pointed that the critical field of the elongated single domain particle calculated by the mechanism of the uniform rotation far exceeds the observed value, and the chain of spheres model is a suitable description of the magnetic behavior of the elongated single domain particle. Jacobs and Bean do not take the exchange interaction between the spheres. For the incoherent modes of magnetization, however, the exchange interactions are important. Ishii and Sato [2] have calculated the effective anisotropy of the chain of spheres with an interface.

2. Theory

Our model incorporates the exchange interaction between magnetic moments of the neighboring spheres along the particle. The exchange field describes the parallel alignment of neighboring particles. The particle diameter is assumed to be sufficiently small such that the exchange energy suppresses the variations across the sample. The exchange field arising from neighboring spheres is $\vec{H}_{exch} = J \sum_{neighbours} v_i \vec{M}_i / M_s$ where J is a phenomenological exchange constant, and $v_i = V_i / \overline{V}$ is the volume of the respective sphere, normalized such that the volume of the sphere with the radius equal with the minor axis of the ellipsoidal particle is unity. Some authors take the exchange field proportional with the magnetic moment of the neighboring particle [3], other authors take it constant [4] and several authors take it inversely proportional to the square of the distance between particles [5]. We have adopted the first form.

In order to extend the model so as to include the shape of the particle we have considered chains of spheres with different size (Fig. 1). We have divided the magnetic particles into many spheres, each of which has an elementary dipole moment. For the calculation we have assumed that the spheres have no magnetocrystalline anisotropy. The total magnetization of the ensemble is

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computed dynamically, integrating the Landau-Lifshitz-Gilbert (LLG) differential equation. The applied field, the dipolar field created by the neighboring particles, and the exchange interactions give the total applied field for each particle. The field for external points created by uniformly magnetized ellipsoids is calculated using the relations given by Tejedor et al. [6].

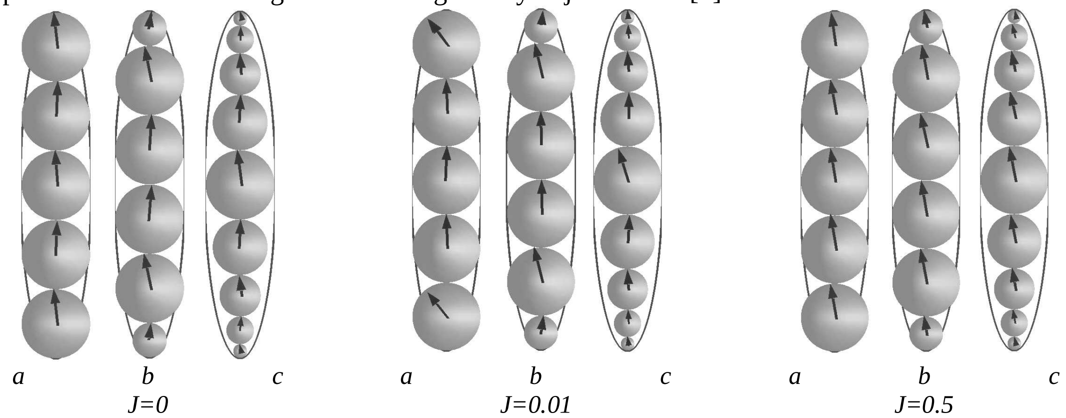


Fig. 1. Magnetization reversal of an aligned chain of spheres.

In addition, we have studied the effect of the exchange interaction on the magnetic behavior. The simulation point out that in the absence of the exchange the moments reversed by a fanning mode, and for $J > 0.2$ moments are strongly coupled giving rise to a high degree of cooperative reversal. For low values of the exchange constant the mechanism of reversal is distinct. In the case of the chain *a* the nucleation of the reversal begins at the ends of the chain, whereas in the case of chain *c*, begins in the center of the chain. The crossover, i.e. the crossing of the hysteresis branches which is observed at the hysteresis loops calculated for angles near 90° between the easy axis and the applied field direction is observed and for chains of spheres. For uniaxial anisotropy the crossover points are explained as the effect of neglecting the higher terms in the series expansion of the anisotropy free energy.

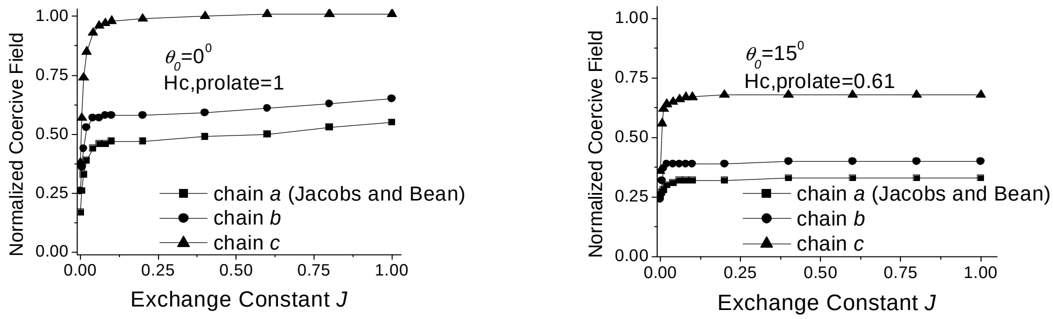
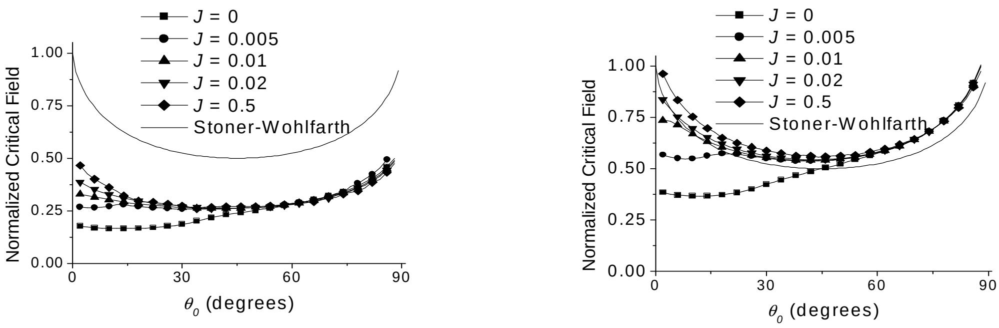


Fig. 2. The critical field vs. the exchange constant.



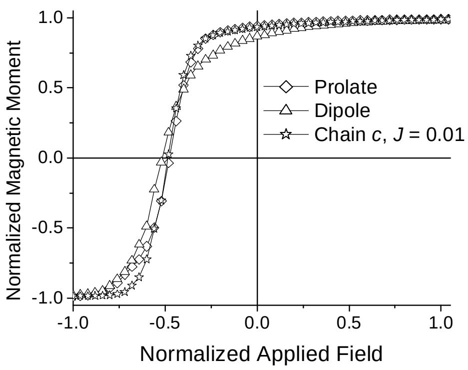
Chain *a* (Jacobs and Bean) Chain *c*

Fig. 3. The critical field vs. the angle θ_0 between the applied field and the axis of the particle.

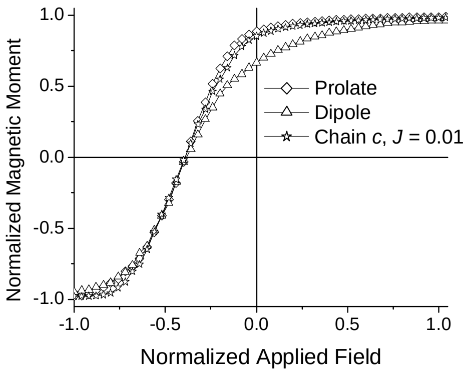
3. Results

In the case of a system of particles the interaction field applied to each particle is calculated in the center of the particle or sometimes is averaged over the volume of particle. In the model of chains of spheres the interaction field is calculated by summing the interactions between elementary dipoles in the opposite. This is a better approximation that in the first cases. The interactions can lead to collective magnetic behavior.

Two kind of geometries are considered: (i) 2D sample for which the position of the particles centers lies randomly distributed in a plane, the axes of the particles lying in the same plane with a Gauss distribution of the direction; (ii) 3D sample for which particles centers lies in a rectangular cell of four-particle width and a Gauss distribution in and out of plane of the easy axes is assumed. Periodic boundary conditions are used to extend the cell for the calculation of the interaction field due to nearest neighbors. The particles were assumed to be single domain.



(a) 2D sample

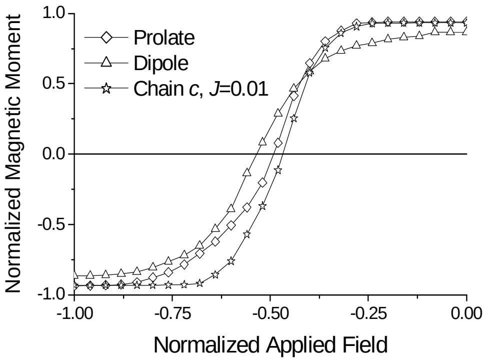


(b) 3D sample

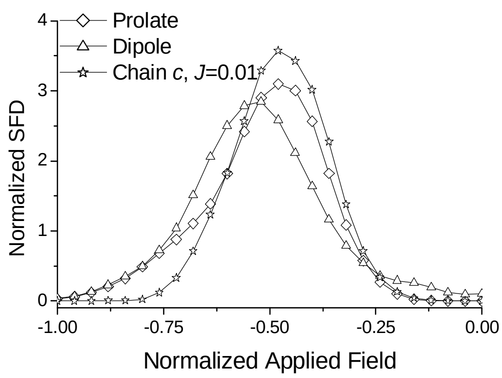
Fig. 4. The upper branch of Major Hysteresis Loop (MHL).

In 3D case the hysteresis loops are less square than in the 2D case for similar parameters because the collective reversal is less important.

The effects of interactions on the energy barrier distribution are evident in the Switching Field Distribution (SFD), which is a measure of the irreversible magnetization changes. The SFD is calculated as the derivative with respect to field of the DC demagnetization remanence curve (DCD).

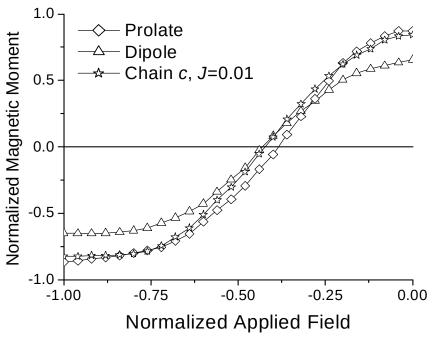


(a) The DCD curves

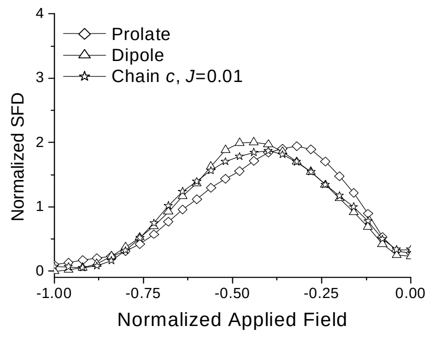


(b) The SFD curves

Fig. 5. 2D sample.



(a) The DCD curves



(b) The SFD curves

Fig. 6. 3D sample.

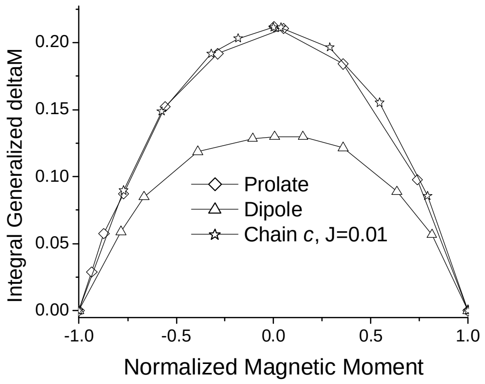


Fig. 7. The Integral Generalized deltaM plots for 3D sample.

To investigate the interactions we have simulated the Integral Generalized deltaM (IGDM) plots [7]. The model of chain *c* gives practically the same result as in the case the field is calculated according to [6].

4. Conclusions

A new model for elongated particles has been developed. Micromagnetics simulations provide a deeper insight into the mechanism of reversal. The exchange between the spheres of the chain was taken into account. The effect of the phenomenological exchange constant was studied. The exchange dependence of coercivity varies depending on the orientation of the particles.

When the particle is divided into more spheres, the calculation becomes more accurate. However, a large number of spheres are not suitable for practical uses because the required calculation power becomes huge. Besides, the model of Jacobs and Bean is applicable only for an integer aspect ratio of the ellipsoidal particle.

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