MICROMAGNETIC MODEL FOR PERPENDICULAR MAGNETIC RECORDING SIMULATION

Fan Quan-You, Li Pu and Zhang Fu-Sheng

Inst. Magn. Rec. Technol., P.O.Box 100, Taiyuan, Shanxi, P.R.China

Abstract----- The micromagnetic model for the computer simulation of perpendicular magnetic recording process has been described in the paper. The algebraic solution of equilibrium equation has also been found, which is suitable for computer arithmetic. The paper not only compared the critical curves of the two models, but also analysed the results of the calculation.

Key words, Micromagnetic model, Computer simulation, Perpendicular magnetic recording

INTRODUCTION

In the computer simulation of magnetic recording process, the first-used vectorial model was the coherent rotation [1], which adopted artificial treatment for the "Coercivity paradox". In recent years the curling model [2] has been used. Based on micromagnetic theory, the paper solves the equilibrium equation by algebraic method, compares the critical curves of the two models in the perpendicular magnetic recording simulation and analyses the hysteretic curves of the two models.

SOLUTION OF EQUILIBRIUM EQUATION

The micromagnetic theory is based on thermodynamical energy minimization principle. In micromagnetics, the magnetization is described by a vector field

$$\vec{M} = M_s \vec{r}(x, y, z) \quad (1)$$

whose magnitude M_s is a constant, but whose direction $\vec{r}$ varies continuously with position.

$$\vec{r} = r_x \vec{i} + r_y \vec{j} + r_z \vec{k} \quad (2)$$

The changes of magnetization can be described by the changes of the direction of magnetization at every point. The region of rapid changes of the magnetization is the transition of recording.

In order to calculate the actual magne-

tic states, we evaluated the minimum of the free energy, with the applied field as a parameter. The total energy consists of (1) the crystalline anisotropy energy, (2) the demagnetizing field energy, (3) the magnetostatic energy, (4) the exchange energy and (5) the magnetoelastic energy.

For simplification, the following assumptions are given:

- (1) The media is consist of N single domain particles of the uniaxial anisotropy and the interaction between the particles is neglected. Since the particle is single domain, the exchange energy term is not counted.
- (2) The shape of particles is considered as the lengthed ellipsoid or the circular cylinder.
- (3) In this work we placed all particles in the x, y plane i.e. 2D-space.
- (4) The magnetoelastic energy will be neglected.
- (5) The magnitude of saturation magnetization of each particle is constant and its direction is relative to easy direction changing with total applied field.
- (6) The easy axis direction of particles is given with certain distribution.
- (7) The switching field distribution is not considered, $H_K = 40000\text{e}$;

The coordinate system of particle is shown in Fig.1. As to the monodomain particle with predominant magnetocrystal ani-

sotropy, its energy density is as the following;

$$E = K \sin^2 (\phi - \alpha) - H_x M_s \sin \phi - H_y M_s \cos \phi \quad (3)$$

Here the crystalline anisotropy energy and the magnetostatic energy are considered (H is for sum of the applied field and the demagnetizing field).

Fig.1 The coordinate system of the particles

The magnetization vector will be in equilibrium with respect to the applied field and the anisotropy when the condition

$$\frac{\partial E}{\partial \phi} = 0, \quad \text{i.e.}$$

$$2k \sin(\phi - \alpha) \cos(\phi - \alpha) - H_x M_s \cos \phi + H_y M_s \sin \phi = 0 \quad (4)$$

To rotate coordinate system and let $\alpha = 0$, thus

$$2k \sin \phi \cos \phi - H_x M_s \cos \phi + H_y M_s \sin \phi = 0 \quad (5)$$

This is more simply expressed by writing

$$H_x / H_k = h_x; \quad H_y / H_k = h_y;$$

where $H_k = 2k / M_s$ so that

$$h_x \cos \phi - h_y \sin \phi - \sin \phi \cos \phi = 0 \quad (6)$$

If given $x = \tan(\phi/2)$, (6) becomes

$$x^4 + \frac{2(h_y - 1)}{h_x} x^3 + \frac{2(h_y + 1)}{h_y} x - 1 = 0 \quad (7)$$

Solving (7) may find four roots x_i ,

thus $\phi_i = 2 \arctan x_i$, $i = 1, 2, 3, 4$.

Two of them have physical reasons and are possible direction of magnetization. If the

rotation is reversible, the angle can be chosen close to the primary direction of magnetization. If the magnitude of the magnetic field exceeds the critical value, the angle should be close to the direction of applied field.

CRITICAL CURVES OF COHERENT ROTATION AND CURLING MODEL

The well-known Stoner-Wohlfarth astroid curve has been obtained by the coherent rotation model [3]. This is a hypercycloid of four cusps (as shown in Fig. 2).

Fig.2 Critical curves of the coherent rotation model

This curve is derived from (3) when

$$\frac{\partial E}{\partial \phi} = 0, \quad \frac{\partial^2 E}{\partial \phi^2} = 0 \quad \text{and} \quad \alpha = 0$$

Within the astroid, only the reversible coherent magnetization rotation is possible; outside the astroid, the irreversible coherent rotation occurs. This curve can be expressed in a function

$$h_y^{2/3} + h_x^{2/3} = 1 \quad (9)$$

The angles ϕ_i of course, can also be found by the tangent from the tip of the field vector to the astroid. If the tip of the field vector is inside the astroid, there are two possible directions of magnetization. While h is outside, there is only one direction of magnetization.

The magnitude of the coercive fields calculated by the coherent rotation model is

much larger than that observed in the concrete media. Under the condition of unspecified physical cause of the reversal nucleation, the astroid curve can be truncated in simple way. Switching would occur while the vertical component of the magnetic field in easy axis direction exceeds the perpendicular coercivity of particles. (see Fig. 2)

The critical curve of the incoherent curling model is an ellipse. Its nucleation value should comply with the following relation:

$$h_y^2/h_c^2 + h_x^2/(1+h_c)^2 = 1 \quad (10)$$

where $h_c = -1.08s^{-2}$, S is the reduced radius, $S=R/R_0$. R is the radius of the particle and R_0 is characteristic radius of material. The reduced radius is regarded as a fitting parameter associated with H_c/H_K . We suppose $H_K = 40000\text{e}$, $H_{c\perp} = 10000\text{e}$, $h_c = -H_{c\perp}/H_K$, then $s = 2.08$.

The critical curves of two models are superposed in order to compare with each other (see Fig. 3)

Fig. 3 Critical curves of the incoherent curling model. In order to compare with the coherent model's, two kinds of curves are superposed together

It is obvious that only near by the hard direction can there be much difference.

MAGNETIZATION BEHAVIOUR OF AN ASSEMBLY OF PARTICLES

In previous section the angle ϕ found are lying on the self-coordinate of particles ($\alpha=0$). After a coordinate transformation, the magnetization of particle assembly can be determined by using the vectorial superpose method in consideration of probability distributions of easy axis. The general scheme of mapping procedure is as follows:
Input field value $h \rightarrow$ transformed to $\tilde{h} \rightarrow$ input to hysteresis model $\rightarrow$ output from model $\tilde{m} \rightarrow$ transformed to m .

The magnetic fields input to the hysteresis model are given by

$$\tilde{H}_y = H_y \cos \alpha - H_x \sin \alpha \quad (11)$$

$$\tilde{H}_x = -H_y \sin \alpha - H_x \cos \alpha \quad (12)$$

The output from model is $\tilde{m}$. Taking account of the distribution of easy axis in accordance with $\cos^{16} \alpha$, the probability function is expressed as $P(\alpha_i)$ and the magnetization behavior of the medium can be determined by the synthetical result of particles assembly, thus

$$M_x = \sum_i P(\alpha_i) M_s \sin(\phi_i + \alpha_i) \quad (13)$$

$$M_y = \sum_i P(\alpha_i) M_s \cos(\phi_i + \alpha_i) \quad (14)$$

$$\text{where } \sum_i P(\alpha_i) = 1 \quad (15)$$

RESULTS AND DISCUSSION

According to the vectorial hysteretic model, the loops of particle depend upon the easy axis directions. Hysteresis loops calculated respectively as $\alpha = 0^\circ, 30^\circ, 50^\circ, 70^\circ$ and 90° are shown in Fig. 4

The hysteretic curves of the medium calculated for two models have also been plotted by Model k-510 Digitizer (see Fig. 5).

It is obvious that there is a little difference for particle assembly of random distribution (the right of Fig. 5), because of their different critical curves. But there is almost no difference for the oriented distribution particle assembly, (the

left of Fig.5), due to the easy directions of the most particles near y axis

As described above, it seems much better to use curling model in the computer simulation of the perpendicular magnetic recording because it has avoided the trouble from the puzzle of the "coercivity paradox"

Fig. 4 The hysteresis loops of the particles of various easy axis

Fig. 5 The loops of the two models based on the different arrangement of easy axis

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