Characteristic Analysis of Magnetic Material's Hysteresis by Preisach Model

Gwan-Soo Park
Dept. of Elec. Eng., Korea Maritime Univ., Pusan 606-791, Korea

Abstract--**This paper presents the new practical method to obtain the Preisach density distribution. The particle coercive density distributions can be obtained from measured initial curve and major loop, and the particle interaction distributions are presumed to be Gaussian distribution based on previously obtained coercive densities in Preisach plane. The implemented values are agreed well with measured major and minor loops, and it is concluded that this method is easy to implement and gives better accuracy than conventional method. In the application of longitudinal high density recording systems, the magnitude of reading signal increases as the media coercivity increases and the media thickness decreases.**

I. INTRODUCTION

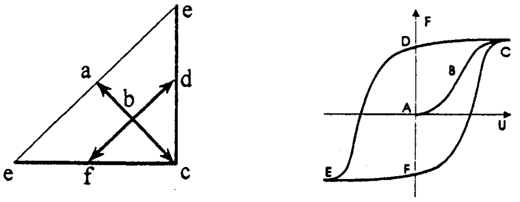
In the analysis of magnetic system including the hard materials, e.g. permanent magnet system or magnetic recording system, the hysteresis characteristics should be analyzed. For the analysis of hysteresis characteristics by Preisach model, the Preisach density distribution D(u,v) should be obtained beforehand. In classical method, D(u,v) is obtained from sets of measured return curves [1]. But it is very hard to measure the return curves because of the abrupt change of hysteresis curves around the coercive fields. Although the 10 return curves with uniform increment of magnetic fields were measured, the only 10x10 dimension of density distribution can be obtained. For the precise analysis of the hysteresis characteristics, the 100x100 dimension of density distribution is needed. But it is very hard to find the appropriate interpolation function for making 100x100 data by 10x10 data. In these reasons, the attempts on classical method to obtain the densities are very seldom.

The simple method to obtain the densities are already presented [2], [3]. In this method, the whole Preisach densities are assumed to be Gaussian. The densities can be obtained from only a few parameters [3], which is too simple to fit the real hysteresis loops. Although the particle interaction densities seem to be Gaussian [4], the particle coercive densities are not always assumed to be Gaussian. And minor loops off the axes can not fit the real curves because the densities in the region where the interaction fields are greater than coercive fields are neglected. For examples the remanent magnetization in major loop is always equal to the saturation magnetization which is not in real materials.

This paper presents the new practical method to obtain the the Preisach density distribution. In this paper, the particle coercive density distributions can be obtained from measured initial curve and major loop, and the particle interaction distributions are presumed to be Gaussian distribution based on the previously obtained coercive densities in Preisach plane. To verify the efficiencies of this implementation, the computed values are compared with measured major and minor loop, and applied to the longitudinal recording systems.

II. DENSITY DISTRIBUTION

In Preisach density plane as in Fig. 1(a), D(u,v) on a-c direction represents the coercive fields, and d-f direction represents the interaction fields. In Everett density plane which means the integral of D(u,v), Everett function E(u,v) on a-c line represents the magnetization M of initial curve as in Fig. 1(b) A-C.



(a) Preisach plane (b) Hysteresis curve
Fig. 1. Densities on Preisach plane and hysteresis curves.

E(u,v) on c-d-e and e-f-c represent the M of major loop as in Fig. 1(b) C-D-E and E-F-C. So, E(u,v) on thick line on Fig. 1(a) can be filled from the measured major loop and initial curve. If we presume the Gaussian distribution on particle interaction field, D(u,v) on d-f line is obtained from Gaussian function as follows;

$$D(S)=K\cdot \mathrm{Exp}[-\frac{(S-S_1)^2}{A}] \qquad (1)$$

where $K=D_1$, $A=\frac{(S_2-S_1)^2}{\ln(D_1/D_2)}$ and D_1,D_2 is the density at S_1,S_2 on d-b or f-b line in Fig. 2.

The presented method is applied to the CoCrTa thin film media. The Preisach plane is divided into 100x100/2 pixel for the implementation. The particle coercive densities on c-d-e and e-f-c in Fig. 1(a) are obtained from major loop in Fig. 3(a), and those on a-b-c are obtained from initial curve.

The particle interaction densities can be obtained in each pixel from Gaussian function and coercive densities as in (1). Fig. 3 shows the implemented minor loop compared with measured loop. In that figure, the major loop is exactly the same as that of measured. The minor loop in Fig. 3(b) is a little different, which seems to be not considered with reversible component of magnetization in implementation.

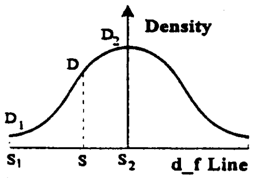
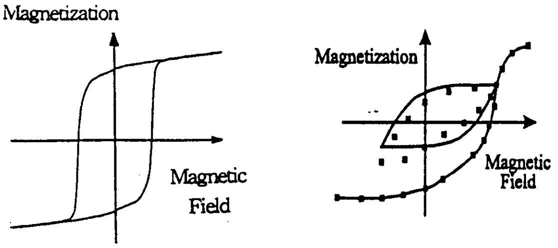


Fig. 2. Interparticle interaction density distribution on the d-f line on Preisach plane in Fig. 1(a).



(a) Measured loop (b) Measured and computed loop
Fig. 3. Comparison of major and minor loop computed(line) and measured(dot point).

III. ANALYSIS WITH HYSTERESIS

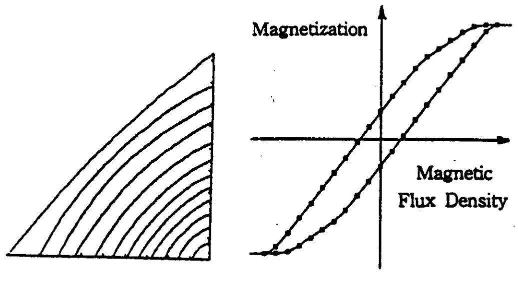
In case the analysis of magnetic system with hard materials, the following equation should be solved.

$$-(\nabla\cdot\nu\nabla)A=J+\nabla\times M \qquad (2)$$

where ν is reluctivity, A magnetic vector potential, J current density and M magnetization. The finite element method is combined with Preisach model. Since M is a function of field, (2) should be solved iteratively [5].

Because of the abrupt change of magnetization around the coercive force in computation, the convergency is sometimes very bad. To improve the convergence and efficiency in computation, M-B variables were used as implementation variables in Preisach model instead of M-H variables [5].

Fig. 4(a) presents the contour line of Everett density obtained from CoCrTa thin film media under the M-B variables. The major loop implemented is agreed very well with that of measured as in Fig. 4(b).



(a) Everett density (b) Major loop
Fig. 4. Contour line of Everett density and major loop implemented(line) and measured(dot point). Evaluation variables are M-B.

IV. PRACTICAL APPLICATIONS

The recording and reading processes in longitudinal recording system are simulated by scalar Preisach modeling and finite element method as in [5]. Because of the scalar Preisach modeling, the only longitudinal component of magnetization was calculated as a function of longitudinal field. Head gap length is 0.3 μm, relative permeability of head 2000, flying hight 0.12 μm and deep gap field 11000 Oe. The magnetic properties of thin film recording media is shown in Table I.

TABLE I

specimen	Hc(Oe)	S	S*	Mr (emu/cc)	t(μm)
I	1200	0.89	0.82	590	0.07
II	1700	0.88	0.91	520	0.06

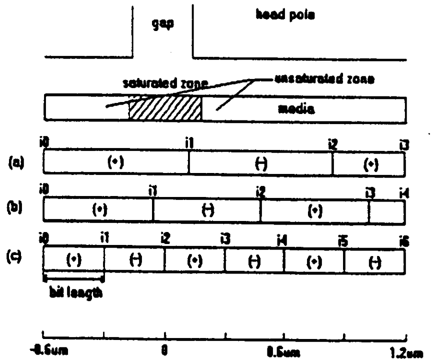
MAGNETIC PROPERTIES OF THIN FILM MEDIA

A. Effects of Recording Density on Minor Loops

Fig. 5. shows the schematic diagram according to the recording densities. The hysteresis behavior of one fixed position moving through the recording zone is described in Fig. 6. When the recording density is low, media follow the major loop because the head field is several times greater than saturation field. But as the density increases, media follows the complex minor loops. So, the minor loop modeling plays an important role in the analysis of high density recording systems.

B. Effects of Media Coercivity on Bit Patterns

To achieve a high density recording, the increase in coercivity of media is necessary. Fig. 7



(a) 35 kFCI (b) 50 kFCI (c) 80 kFCI

Fig. 5. Schematic drawings of saturated zone and bit length according to the head position in each densities.

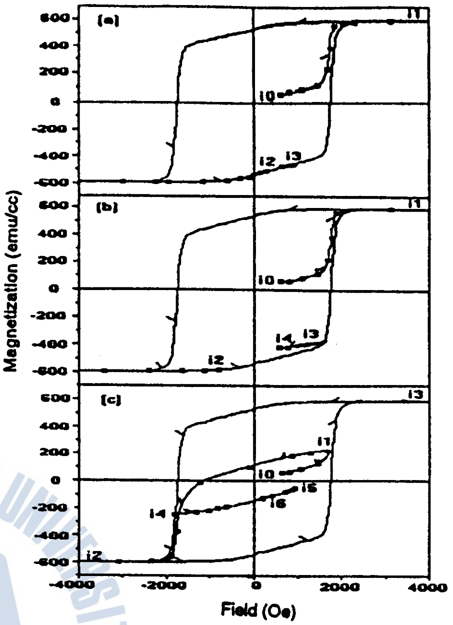


Fig. 6. Minor loop behavior of one position on the media at different recording densities in Fig. 5. As the density increases, the minor loop behavior of media becomes more complex.

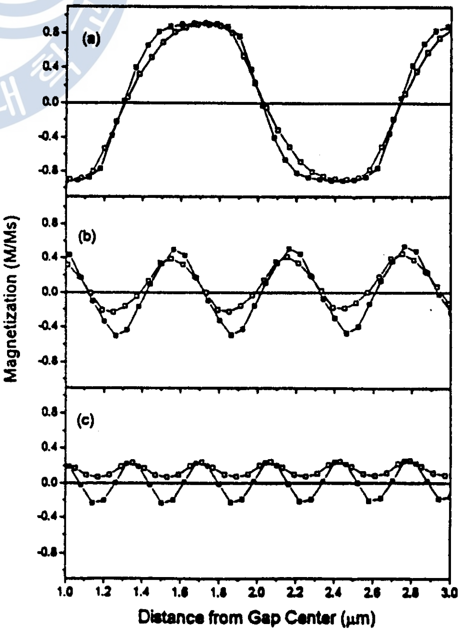


Fig. 7. Bit patterns of recording media with 1200 Oe (white square) and 1700 Oe(black square) in 35 kFCI(a), 80 kFCI(b) and 140 kFCI(c). In high density recording, the media with low coercivity is not recorded.

represents bit patterns on media with 1200 Oe (white square) and 1700 Oe (black square) in 35 kFCI (a), 80 kFCI (b) and 140 kFCI (c). In high density recording as in Fig. 7(c), the magnetization of media is always plus which means the media with low coercivity is not recorded. This is because the broadening of the bit pattern is more severe in low coercivity materials as the recording density increases.

C. Effects of Media Thickness on Reading Voltage

To achieve a high density recording, the decrease in thickness of media is necessary. Fig. 8 represents bit patterns on media with 0.2 μm (black circle), 0.06 μm (black triangle) and 0.03 μm (black circle) in 35 kFCI (a), 80 kFCI (b) and 140 kFCI (c) at the same coercivity. Fig. 9 represents the tendency of reading voltages as the thickness of media in high recording density. In low density, the magnitude of reading voltage is increasing as the media thickness increases. But in high density, the magnitude of reading voltage is decreasing as the media thickness increases. This is because the slope of transition is steep and the width of transition is small in thin media at high densities.

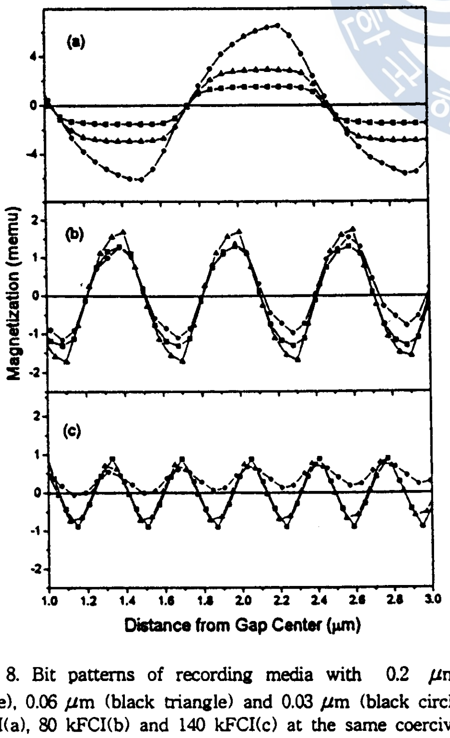


Fig. 8. Bit patterns of recording media with 0.2 μm (black circle), 0.06 μm (black triangle) and 0.03 μm (black circle) in 35 kFCI(a), 80 kFCI(b) and 140 kFCI(c) at the same coercivity.

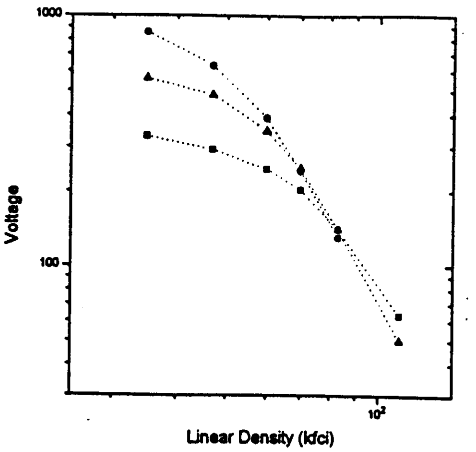


Fig. 9. Effects of media thickness on reading voltage at the same condition of Fig. 8. In high density, the reading voltage of thick media decreases more rapidly than that of thin media.

V. CONCLUSIONS

In the practical analysis of hysteresis characteristics by Preisach model, the first and the most difficult problem is the method to obtaining the density distribution from a given materials. The presented method in this paper is easier than that using the return curves, and gives more accurate result than that using the whole Gaussian function. In the application of recording systems, although the method described in this paper includes the limitation of scalar modeling, the tendencies of the effects of recording media coercivity and thickness are successfully analyzed. It is concluded that the presented method in this paper is very convenient and practical in use.

REFERENCES

[1] D. L. Atherton, et.al., "A New Approach to Preisach Diagrams," *IEEE Trans. on Mag.*, vol.21, no.3, pp1856-1865, May 1987.

[2] F. Vajda and E. Della Torre, "Measurements of output dependent Preisach function," *IEEE Trans. on Mag.*, vol.27, no.6, pp. 4757-4762, November 1991.

[3] F. Vajda , J.Oti, M. Pardavi and E. Della Torre, "Experimental verification of a vector Preisach model," *J. Appl. Phys.* 69 (8),15 April 1991.

[4] E. Della Torre, "Effect of interaction on the magnetization of single domain particles," *IEEE Trans. Audio Electroacoust.*, 14(1965), 86-93.

[5] G. S. Park, S. Y. Hahn, K. S. Lee and H. K. Jung, "Implementation of hysteresis characteristics using Preisach model with M-B variables," *IEEE Trans. on Mag.*, vol. 29, no.2, pp. 1542-1545, March 1993.