ANGULAR DEPENDENCE OF THE MAGNETIC PROPERTIES IN RECORDING MEDIA

Dennis E. SPELIOTIS and J. Patrick JUDGE

Digital Measurement Systems, Inc., 8 Ray Avenue, Burlington, MA 01803, USA

Abstract-- The writing process in magnetic recording is vectorial, with the head field changing from longitudinal to perpendicular as the media moves by the gap of the recording transducer. Therefore, it is important to study the angular dependence of the magnetic properties of the media in order to understand the nature of the writing-demagnetization processes. To correctly compensate for the demagnetization fields in out-of-plane measurements it is necessary to use vector magnetometry and to include all the components of the demagnetizing fields, except that for the perpendicular direction it is possible to obtain accurate corrected values of the remanence coercivity by using a conventional single-axis VSM. Measurements of this parameter for many state-of-the-art recording media are given, revealing a significant problem for longitudinal thin film media.

INTRODUCTION

Magnetic recording media employ thin films or relatively thin particulate coatings, and thus have a preference for their remanent magnetization to lie in the plane of the media. This preference may be further enhanced if the individual easy axes of the particles or crystallites are also in the plane, or may be offset if they are out of the plane. Coupled with this magnetic anisotropy of the media we have the vectorial nature of the recording head field which changes direction from longitudinal to perpendicular as the media move past the gap of the recording transducer. Therefore, the angular dependence of the magnetic properties of the media is of singular importance in understanding the writing-demagnetization processes. Since the remanence coercivity H_r represents the actual switching criterion of the media, we concentrated our major emphasis in this study to the determination of the angular variation of this parameter.

The measurement of the angular dependence of the magnetic properties in the plane of the media is quite straight forward, but the out-of-plane measurements are complicated by the presence of the demagnetizing fields. For uniaxial, longitudinally oriented media, it has at times been assumed that the magnetic properties are iso-

tropic in a plane perpendicular to the orientation axis, but this assumption is not valid for most media, since the distribution of the particle or crystallite anisotropies in the plane orthogonal to the axis of orientation is not uniform.

To compensate for the inherent demagnetizing fields in out-of-plane measurements it is necessary to use vector magnetometry [1-4] in order to determine the magnitude and the angle of the effective field H_e . The main complication arises from the fact that as the magnitude of the externally applied field H_a changes, both the magnitude and the angle of the effective field change. It thus becomes necessary to use heuristic iterative techniques [4] and continuously readjust the magnitude and the angle of the applied field so as to vary only the magnitude of the effective field but keep its angle with respect to the sample plane constant. The measurement is quite complicated and lengthy, prompting us to investigate some alternative approximate techniques that may yield useful--even though not exact--results, and to determine the conditions under which these simplified methods for demagnetization corrections may be used instead of the full vectorial approach.

In the following sections we first describe the different simplified models for partially compensating

the demagnetizing fields. We then present the experimental measurements of the angular dependence of H_x and H_c in the plane of various longitudinally oriented recording media, followed by out-of-the-plane measurements of H_x for longitudinally and perpendicularly oriented particulate and thin film media, along with the corrections for demagnetization based on the simplified models. Finally, we assess the conditions of applicability of the simplified models.

MODELS FOR DEMAGNETIZATION FIELD CORRECTION

The only way to completely and correctly compensate for the demagnetizing fields is to use vector magnetometry in order to calculate the effective internal field H_e acting on the sample when an external field H_a is applied at some angle with respect to the plane of the sample. As pointed out above, however, this is rather complicated and time consuming, and we would like to explore whether, and under what conditions the following three simplified models in measuring $H_x(\Omega)$ may yield useful results.

Referring to Fig. 1, we start by first measuring the uncorrected angular variation of the remanence coercivity $H_r'(\Omega)$, with the external fields applied along the x-axis, and the sample plane rotated to an angle Ω with respect to the applied field. In our notation here we use the accent (') to denote uncorrected values of H_x , the subscripts d and e to designate the demagnetizing and the effective fields, respectively, and the symbols ($\perp$) and ($\parallel$) to designate directions perpendicular and parallel to the sample plane, respectively.

(A) M_x or hard-axis model

In this simplified model we assume a well-aligned sample with uniaxial anisotropy, and its magnetization reversal proceeds by rotation. It is then reasonable to assume that with $H_x'(\Omega)$ applied, the average magnetization is along the hard axis of the par-

Fig. 1. Vector geometry of sample showing the applied and the demagnetizing fields.

ticles or crystallites, and when $H_x'(\Omega)$ is reduced to zero, the magnetization rotates back with equal probability along the plus and minus directions of the axis of alignment. The sample would thus exhibit zero remanence along any axis in the plane or out of the plane after the removal of each particular $H_x'(\Omega)$. We distinguish two cases:

1. Easy axis in the sample plane

With $H_x'(\Omega)$ applied we only have $M_{\perp}$, and the component M_x along the field axis that would be measured by a conventional single-axis VSM is:

$$M_x = M_{\perp} \sin \Omega \quad (1)$$

Therefore, if we neglect the y-component of the demagnetizing field $H_{d,y}$ (in order to simplify the problem) we obtain for the corrected value of the remanence coercivity:

$$H_x(\Omega) = H_x'(\Omega) - 4\pi M_x \quad (2)$$

2. Easy axis $\perp$ to sample plane

In this case, with $H_x'(\Omega)$ applied we only have $M_{\parallel}$, and

$$M_x = M_{\parallel} \cos \Omega \quad (3)$$

Since there are no demagnetizing fields,

$$H_x(\Omega) = H_x'(\Omega) \quad (4)$$

(B) M_x Model

With $H_x'(\Omega)$ applied, we assume that M_x is the only significant component of the magnetization. Thus,

$$M_{\perp} = M_x \sin \Omega \quad (5)$$

By again neglecting $H_{a,y}$ in order to simplify the problem we obtain:

$$H_r(\Omega) = H_r'(\Omega) - 4\pi M_r \sin^2 \Omega \quad (6)$$

(C) Partial vector model

The two simple models (a) and (b) above require only a conventional uniaxial VSM. For this and the following model, we require a biaxial (vector) VSM[1,2]. With $H_r'(\Omega)$ applied we measure M_x and M_y , compute the vector $\vec{M} = M/\alpha$, where $M = (M_x^2 + M_y^2)^{1/2}$ and $\alpha = \tan^{-1}(M_y/M_x)$, and obtain

$$M_L = M \cos(90 - \Omega - \alpha) \quad (7)$$

If we again neglect $H_{a,y}$ for simplicity, we finally compute the corrected remanence coercivity

$$H_r(\Omega) = H_r'(\Omega) - 4\pi M_L \sin \Omega \quad (8)$$

(D) Full vector model

In all three simplified models above we assumed that we can neglect the y-component of the demagnetizing field $H_{a,y}$, but in general this assumption is not justified [4]. Therefore for the general case we must determine the effective field H_e and the angle β it makes with the sample plane. Unfortunately, both H_e and β vary as the applied field changes in magnitude, thus requiring laborious trial and error measurements for the correct determination of $H_r(\Omega)$. This will form the subject of a future publication.

EXPERIMENTAL RESULTS AND DISCUSSION

Angular Measurements in the Plane

We first show the experimental results of the angular dependence of H_c and H_r in the plane of different recording media with in-plane anisotropy (perpendicular and isotropic media, of course, have no in-plane angular variations of their magnetic properties). The results are shown in Figs. 2-7 for the most common types of media. Co-gamma (SVHS), metal particle (8mm), and Ba-ferrite experimental longitudinally oriented (not very well) tape show only a small increase in H_r at 90° , while CrO_2 tape shows a

Fig. 2. In-plane angular dependence of H_c and H_r for Co-gamma (SVHS) tape.

Fig. 3. In-plane angular dependence of H_c and H_r for an experimental CrO_2 tape.

Fig. 4. In-plane angular dependence of H_c and H_r for Hi8mm MP tape.

Fig. 5. In-plane angular dependence of H_c and H_r for an experimental BaFe longitudinal tape.

Fig. 6. In-plane angular dependence of H_c and H_r for longitudinal BaFe rigid disk.

Fig. 7. In-plane angular dependence of H_c and H_r for anisotropic thin film rigid disk.

large increase, and Ba-ferrite rigid disk media show a very large increase. The Ba-ferrite rigid disk media have much better orientation compared with the Ba-ferrite tapes, and this accounts for the much larger DH_r of the former, where DH_r is defined by:

$$DH_r = [H_r(90^\circ) - H_r(0^\circ)] / H_r(0^\circ) \quad (9)$$

In sharp contrast to the particulate media, anisotropic rigid disk sputtered thin film media show a substantial drop in H_r from the circumferential to the radial directions.

Angular measurements out of the plane

We measured the out of plane angular variation of the remanence, coercivity of various particulate media, and applied the approximate demagnetization corrections according to models A, B, and C described in the previous section. All the models agree with each other as well as with the full vector model D at 0° and at 90° (perpendicular direction). For other angles, the demagnetization corrections provided by the three simplified models vary over a fairly wide range, depending on the type of media [3]. Of the three simplified models, we might expect that model C may provide the best approximations for the corrected H_r values, and the best criterion to use in assessing how good these approximations are is how small is the angle $(\Omega - \beta)$ between the applied field $H_r(\Omega)$ and the effective field H_e ; the smaller the angle, the better the approximation. Depending on the type of media and the direction of magnetic orientation we can make the following statements:

(a) Longitudinally oriented particulate media

These include Co-gamma, CrO_2 , Metal Particle 8mm (MP), and experimental Ba-ferrite tapes. The angular deviation between H_e and H_r is fairly small (up to 12° maximum). Correction models B and C agree quite well.

(b) Isotropic particulate media

These include 4MB Ba-ferrite floppy disk media and random in-plane MP floppy disk media. The angular deviation between H_e and H_r is larger than in (a) above (up to about 20° maximum), but the corrections provided by models B and C are almost identical.

(c) Perpendicularly oriented media

These include experimental Ba-ferrite particulate and sputtered CoCr thin film media. The angular deviation between H_e and H_r is quite small (up to 5° max), but the agreement between correction models B and C is not very good.

(d) Thin film longitudinal media

These include the typical high coercivity sputtered thin film media used for small rigid disks, including CoCr-Ta and CoNiCr compositions. Here, the angular deviation between H_e and H_r is very large, and only the full vector correction (Model D) can be used for angles other than 0° and 90°.

In Table 1 we list the values of the remanence coercivities in the longitudinal and perpendicular directions for a representative collection of typical high density recording media (both commercial and experimental), and also the computed DH_r values.

The co-modified iron oxide media (CoFe) used for SVHS video show a small positive DH_r , even though they have excellent longitudinal orientation. The CrO_2 and MP tapes have large positive DH_r values. The Ba-ferrite longitudinally oriented experimental tape was not very well oriented (longitudinal $SQ=0.67$) because a good percentage of the Ba-ferrite platelets are apparently tilted towards the surface of the substrate film, thus resulting in a relatively small DH_r value. If this tilting of the Ba-ferrite platelets can be avoided, the DH_r values would increase dramatically, and would surpass those of any other medium. The isotropic Ba-ferrite floppy disk sample shows a negative DH_r , because it is not really

Table 1
Remanence Coercivity Variation of Different Recording Media

Recording Medium	$H_r(//)$ Oe	$H_r(\perp)$ Oe	DH_r (%)
CoFe(SVHS) (//)	942	1006	+6.8
CrO_2 (Exptl.) (//)	596	800	+34.2
MP(8mm) (//)	1544	2230	+44.4
BaFe(Exptl.) (//)	1344	1460	+8.6
BaFe(4MB) (Isotropic)	734	627	-14.6
BaFe(Exptl.) ($\perp$)	1790	1274	+40.5
CoCr(Exptl.) ($\perp$)	2169	1616	+34.2
Thin Film A (//)	1332	730	-45.2
Thin Film B (//)	1451	987	-32.0

isotropic. Apparently, a large number of the platelets tend to tilt towards the substrate.

The perpendicularly oriented media (both the Ba-ferrite particulate and the CoCr sputtered thin film types) show a large increase in H_r from the easy axis ($\perp$) to the hard axis ($//$).

The most serious problem occurs in the sputtered longitudinal thin film media used for rigid disk applications. In Table 1 we show two examples of such media: Film A with high in-plane circumferential orientation, and Film B which is isotropic in the plane. Both of these thin film media show large negative DH_r values.

The implications of the angular variation of H_r out of the plane are very important with respect to recording demagnetization, while the angular variation of H_r in the plane directly affects side-track writing at high track densities. To reduce or eliminate the effects of these problems it is very desirable to have large posi-

tive DH_x values in the perpendicular and also in the transverse directions. Our findings show that longitudinal thin film media face a serious problem with respect to these considerations, since their remanence coercivities tend to decrease significantly as the angle is changed from the easy to the hard directions of the media.

CONCLUSIONS

The angular dependence of the remanence coercivity of magnetic recording media has a direct and significant effect on their recording performance. The variation of H_x in the plane affects side-track writing, while the variation of H_x out of the plane affects recording demagnetization.

In this study we measured the in-plane variation of H_x for various state of the art anisotropic media, and found a very large increase for well-oriented Ba-ferrite and CrO_2 media, and a moderate increase for MP and Co-gamma tape media. Sputtered longitudinal thin film media exhibit a negative DH_x in the plane, making them more susceptible to side-track writing.

We also measured the out of plane angular variation of H_x and used different simplified models to compensate for the demagnetizing fields. Again we found a serious problem in the longitudinal thin film media, where their large negative DH_x values render them vulnerable to recording demagnetization effects. The correct compensation for demagnetizing fields in out-of-plane measurements requires the use of vector magnetometry with full consideration for all the components of the demagnetizing field.

REFERENCES

- [1]. K. Ouchi and S. Iwasaki, IEEE Trans. Magn., vol. 24, pp. 3009-3011, November 1988.
- [2]. D. Speliotis, D. Bono, and P. Judge, J. Magn. Soc. Japan, vol. 13, supplement No. S1, 1989.
- [3]. D.E. Speliotis and J. P. Judge, paper EB-11 presented at the joint MMM/Intermag Conference, Pittsburgh, PA, June 1991.
- [4]. J.P.C. Bernardis and H.A.J. Cramer, paper CE-15 presented at the joint MMM/Intermag Conference, Pittsburgh, PA, June 1991.
- [5]. H.N. Bertram, IEEE Trans. Magn., vol. 20, pp. 2094-2104, November 1984.
- [6]. D.E. Speliotis, J. Appl. Phys., vol. 63, pp 3432-3434, April 1988.