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Vectorial measurements of the angular coercive field

E.O. Samwel[a,*], T. Bolhuis[b], D. Speliotis[a], J.C. Lodder[b]

[a]*Digital Measurement Systems division of ADE Technologies, Inc., 77 Rowe Street, Newton, MA 02166, USA*
[b]*MESA Research Institute, University of Twente, P.O. Box 217, 7500 AE, Enschede, Netherlands*

Abstract

Two of the most important parameters in magnetic measurements are the coercive field, H_c, and the remanent coercive field, H_r. In this paper we will look at these parameters in relation to vector measurements taken at an angle with the (mean) anisotropy direction. We will show that the definition and interpretation of these parameters should be reconsidered for angular measurements. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

Due to its importance for recording performance, the coercive field (H_c) is traditionally one of the most frequently measured and specified parameters for magnetic recording materials. In the literature, the measurement of the angular variation of H_c has been used as a method to discriminate between various magnetization reversal modes [1]. This is based on the assumption that H_c is the mean switching field in the magnetic material. The angular variation of the mean switching field is compared to the angular variation of the theoretical switching field for different reversal modes and from that the reversal mode is determined. Presently the remanent coercive field, H_r, is seen as the real switching field, differing from H_c by the fact that only irreversible magnetization changes are taken into account and therefore being more representative of the recording process.

When studying the recording process in detail, one will find that during this process the recording medium is subjected to a sequence of vector fields with changing amplitude and direction. The areas before and behind the write head are subjected to fields with a varying angle out of the plane and the areas on the sides of the head are subjected to fringe fields that have an angle with the direction of medium motion. These fields can influence the shape and size of the written transitions. Because of this, it is important to investigate the magnetic behavior of recording media under different angles of the applied field. To get a complete picture of the magnetic behavior under these circumstances, it is important to use a vector measurement system such as a vector VSM.

In this paper we will investigate the angular variation of some well known recording materials and show that H_c is lower than the mean switching field for measurements taken at an angle to the effective anisotropy (easy axis) direction. The field at which the magnetization vector reaches its minimum is a much better measure of the mean switching field. A similar phenomenon is demonstrated for the remanent coercive field.

2. The coercive field

Although H_c is generally defined as the field at which the net magnetization is zero, such a field does not exist when the measurement is taken at an angle to the effective anisotropy direction of the material. The magnetization vector of the material will decrease in amplitude and rotate but it will not become zero (as shown in

* Corresponding author. Tel.: + 1-617-831-8010; fax: + 1-617-831-8195; e-mail: esamwel@dms-magnetics.com.

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Fig. 1). Due to the rotation of the magnetization vector, at a certain field the magnetization vector will be completely perpendicular to the applied field. On a scalar measurement system this is observed as a zero magnetization. Therefore, the correct description of the way the coercive field is presently always used is the field where the component of the magnetization in the direction of the applied field becomes zero.

At the coercive field, generally less than half of the particles (or grains) have reached their switching fields, as is illustrated in Fig. 2. The magnetization vector of the individual particles will always point in a direction determined by the applied field, the anisotropy of the particle, the interaction field and the demagnetizing field. In general this means that the magnetization vector of the average particle will point somewhere between the field direction and its anisotropy direction. As soon as the particle magnetization vector reaches an angle of 90° with the field, its magnetization will flip. In Fig. 2 we see a typical situation that occurs when the field applied under an angle with the easy axis reaches $-H_c$ (coming from positive saturation). At saturation all particle magnetization vectors will point in the same direction. If the field is now decreased towards the negative coercive field, many particles will reach their individual switching fields and their magnetization will 'flip' (change from positive to negative). The magnetization vector sum of all the 'not yet flipped particles' will point in a direction between the easy axis and the direction perpendicular to H (otherwise the magnetization would be flipping). The magnetization

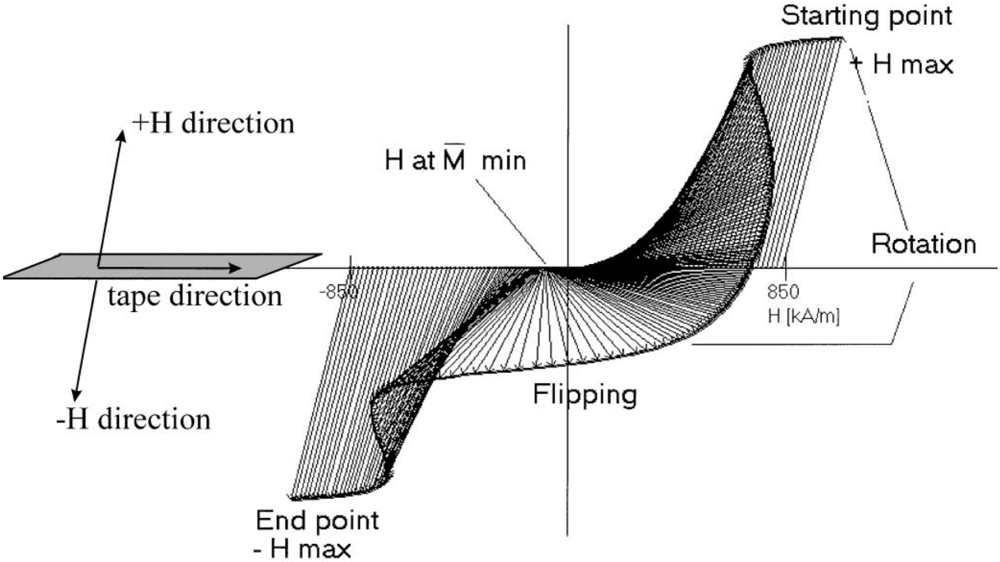

Fig. 1. Magnetization reversal in a standard audio tape when measured under an 80° angle to the plane. For the high fields the magnetization vector aligns with the field. When the field decreases the magnetization vector decreases in length and rotates but never becomes zero.

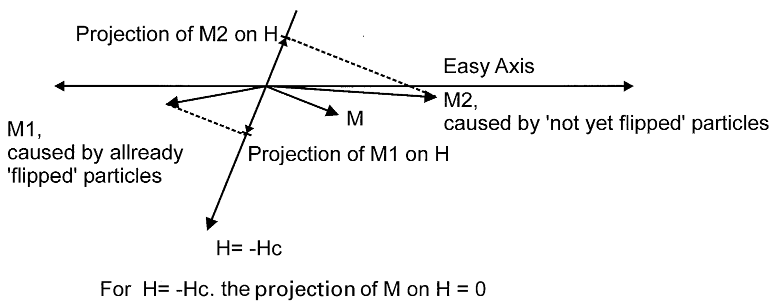

Fig. 2. The situation at the negative coercive field (coming from positive saturation), where the components of the magnetization vector parallel with the field of the 'flipped' and 'not yet flipped' particles compensate each other, even though less than half of the particles have 'flipped'.

vector sum of all the 'flipped particles' will point in a direction between the (average) anisotropy direction and the field direction, (on the opposite side of the field). At H_c, the components of each magnetization vector parallel with the field compensate each other (by definition). From the figure we can see that at H_c the lengths of the two vector sums must always be unequal, unless they are both parallel with the anisotropy direction. In all other cases, the length of the vector sum for the 'not yet switched particles' will be longer than the length of the magnetization vector for the switched particles. All of this means that at H_c less than half of the particles have switched.

From the above and from Fig. 1, we conclude that a better representation of the 'mean switching field' for angular measurements is given by the field at which the magnetization vector reaches its minimum length.

3. The remanent coercive field, H_r

Because the remanent coercive field is determined by irreversible magnetization changes only rather than irreversible and reversible magnetization changes together (as is the case for the coercive field) it is more relevant for the recording process. This brings up the question if the remanent coercive field also has to be reconsidered for vector measurements under an angle with the easy axis direction.

Theoretically, if interactions are ignored and if the remanent magnetization direction for each particle is determined solely by its anisotropy direction, the field at which the remanent magnetization vector reaches a minimum length should be equal to the remanent coercivity. This results from the fact that the sum vector for both 'flipped particles' and the 'not yet flipped particles' will point along the anisotropy axis (according to the previously defined assumptions). Therefore, for a zero remanent magnetization (in H_r) the vectors for each of these groups of particles should have an equal length.

4. Measurement results and discussion

Using both a commercial Digital Measurement Systems (DMS) vector VSM and the vector VSM described in Ref. [2] we measured the angular variations of H_c, H_r and the introduced parameters $H_{at|M|min}$ and $H_{at|Mr|min}$. The latter two parameters represent the field at which the magnetization vector reaches a minimum length in the hysteresis loop and DCD remanence measurement, respectively. Measured results are shown for a single-layer Metal Evaporated (ME) videotape and a standard VHS videotape. The ME tape has an easy axis direction roughly -20° out of the plane (if no correction for the demagnetizing field is taken into account). For ME tape measurements are shown for an angular variation in the plane and out of the plane, for the VHS tape only an angular variation in the plane of the sample is presented.

Note that normally when measurements are performed where the magnetization has an angle with the plane of the medium, a correction for the demagnetization has to be applied, as proposed in Ref. [3]. This has not been done here (but will be done in a future paper). However, we will compare our results to demagnetization corrected results as presented in Ref. [3].

When we start looking at the out-of-plane results (Fig. 3) obtained on the ME tape, we see an enormous difference between the $H_c(\alpha)$ and the $H_{at|M|min}(\alpha)$ plot ($H_{at|M|min}$ is the field at which the magnetization vector reaches its minimum length). The $H_c(\alpha)$ plot by approximation shows a $\cos(\alpha)$ behavior, where the $H_{at|M|min}$ plot by approximation follows an $1/\cos(\alpha)$ behavior. This is exactly the same behavior as was noted for the demagnetization corrected $H_c(\alpha)$ plots as shown in Ref. [3], to which the plots show a very strong similarity. Further research will have to be conducted before any strong conclusions can be drawn on whether this will be true for all materials. When comparing the $H_r(\alpha)$ and the $H_{at|Mr|min}(\alpha)$ plots, we see a much smaller difference, as was predicted from the theory. We also note that the difference between the $H_{at|M|min}(\alpha)$ and the $H_r(\alpha)$ is much smaller than the difference between $H_c(\alpha)$ and $H_r(\alpha)$, thus supporting the statement that the field where the magnetization vector reaches its minimum is a much better representation for the (mean) switching field than H_c. We can also see that fields under an angle with the plane such as seen behind the write head, will not disturb a written transition unless these fields are significantly larger than the in-plane coercive field.

Fig. 4 shows the angular variation of the same parameters when the field is rotated in the plane of the ME tape. The interpretation of this data is more complicated because part of the vector information is missing due to a lack of z-coils in the VSMs we used. The out of plane component of the magnetization (due to the tilted anisotropy direction) will cause a demagnetizing field that might have influenced the measurement results considerably. Despite or because of this, we see angular variations of H_c and $H_{at|M|min}$ that are much closer to each other than was the case for the out of plane measurement. The difference between the latter parameter and H_r is much larger in this measurement, which indicates that also $H_{at|M|min}$ is still influenced significantly by reversible magnetization changes. We also see that in this case the difference between H_r and $H_{at|Mr|min}$ is significantly larger than in the measurement taken out of the plane of the film. The exact reason for this is unclear to us at the moment but might be related to a combination of the demagnetizing field and the fact that the fields are

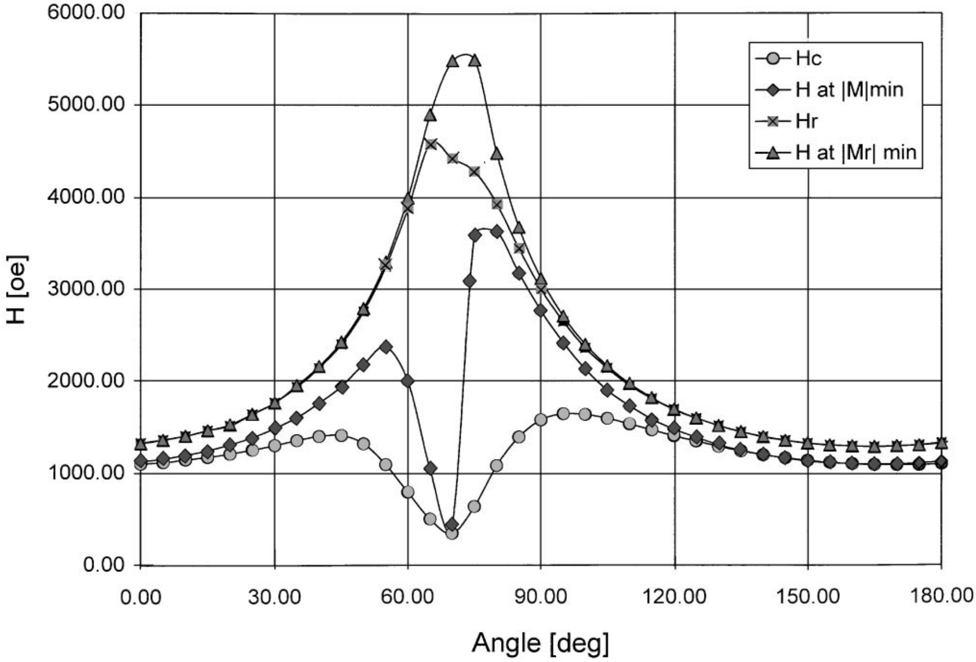

Fig. 3. Angular variation of H_c, $H_{at|M|min}$, H_r and $H_{at|Mr|min}$ for a range of angles out of the plane of a single layer ME videotape.

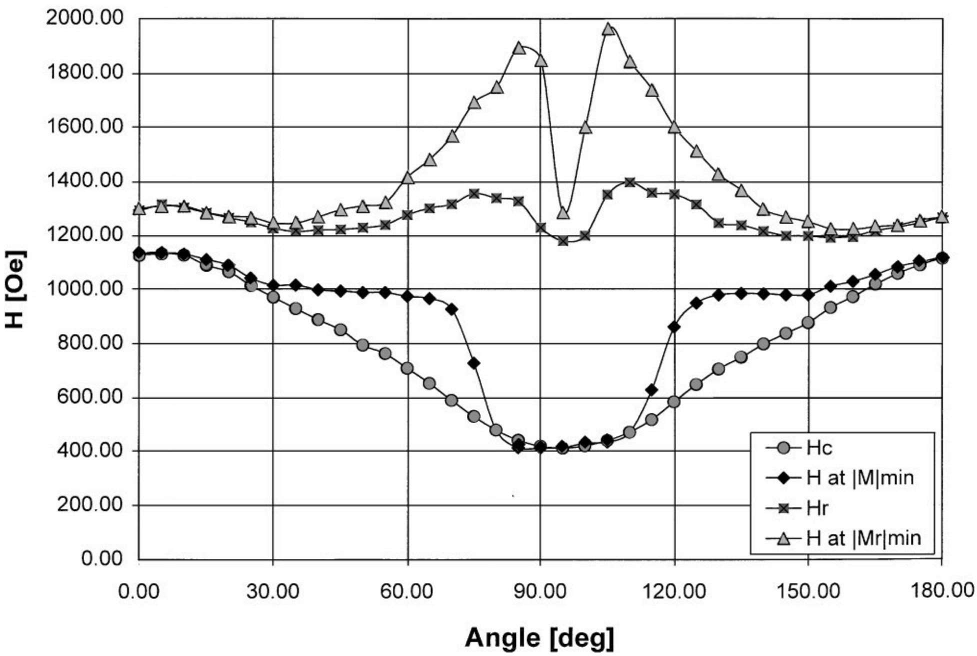

Fig. 4. Angular variation of H_c, $H_{at|M|min}$, H_r and $H_{at|Mr|min}$ for a range of angles in the plane of a single layer ME videotape.

applied under 2 angles to the anisotropy direction, since the anisotropy direction is out of plane.

The interpretation of the measurement results in Fig. 5 is not hindered by the complicated factors that influence Fig. 4. The H_r plot here has a more standard shape, where we can see that the field necessary for the irreversible change of the magnetization at least partially has to be provided in the anisotropy direction. This can

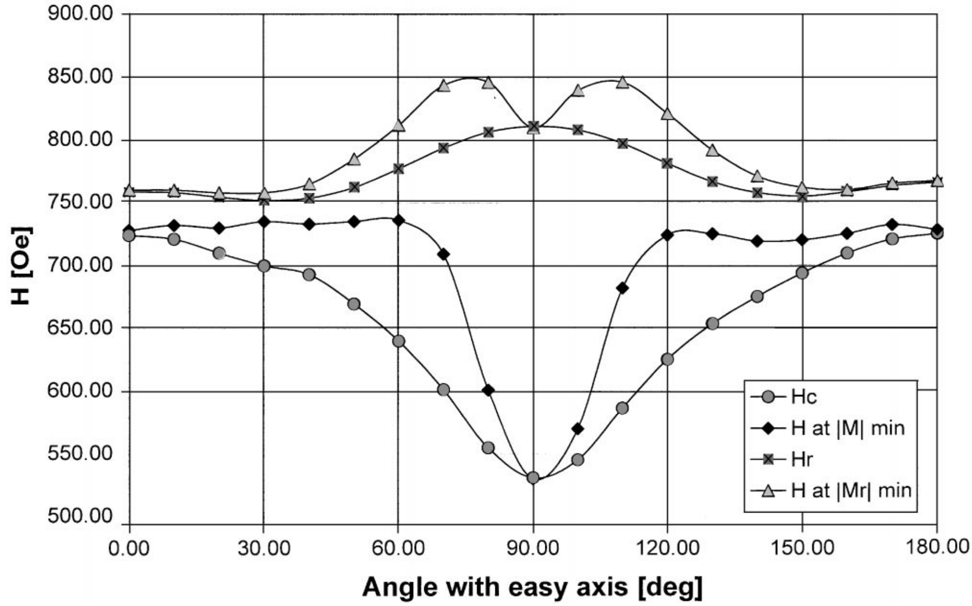

Fig. 5. Angular variation of H_c, $H_{at|M|min}$, H_r and $H_{at|Mr|min}$ for a range of angles in the plane of a standard VHS videotape.

be seen because the shape of the H_r curve and, even more, the shape of the $H_{at|Mr|min}$ curve partially follow the $1/\cos(\alpha)$ behavior, suggesting that the energy for the reversal originates from the projection of the applied field on the anisotropy direction. We can also see here that the differences between the H_c and $H_{at|M|min}$ curve are comparatively small here, which might be caused by a different reversal mechanism.

5. Conclusions

We have seen that the field at which the magnetization vector length reaches its minimum differs from H_c, when the measurement is taken under an angle to the anisotropy direction. This field is a better representation for the mean switching field than H_c but cannot replace H_r. For out of plane measurements the results are much more dramatic than for in plane measurements. Even more important, for the out of plane measurement shown here, the result was very similar to the results for the angular variation of the coercive field when corrected for the demagnetizing field. More research is necessary in this area to further develop the interpretation of these results and to increase the understanding of vector magnetization behavior.

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