Application of the Variable Variance Hysteresis Model to Co-Cr Perpendicular Recording Media

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Abstract—The variable variance model is a Preisach-type model which has been shown to be applicable to artificial magneto-optic perpendicular recording media. In this paper, this model is extended to Co-Cr perpendicular media. It is found that, for this media the variance in the interaction field is larger in the saturated state than in the demagnetized state. More general functional dependencies on the magnetization are discussed.

I. INTRODUCTION

The complete-moving-hysteresis (CMH) model for ferromagnetic media and its robust parametric identification has been presented [1]. It was able to accurately describe the magnetization behavior of longitudinal particulate recording media. Using an artificial magneto-optic medium [2], it has been shown that, for perpendicular media, the standard deviation of the interaction field is magnetization dependent. In the case of the artificial media [3], the variance dependence on magnetization appears to be linear and is smaller in the demagnetized state. For the Co-Cr media, it is seen that the variance also depends upon the magnetization, but in this case the demagnetized state has the smaller variance.

In perpendicular media, the demagnetizing field shears the hysteresis loop. It has been shown that this shearing depends upon the demagnetizing factor, the thickness and the magnetic properties of the film [4]. These demagnetizing effects will be combined with the moving parameter when fully describing the model. In this paper, we shall describe this media in terms of the variable variance model. In addition to the identification of the parameters of the CMH model, one now has to also specify the variation of the standard deviation of the switching field, \( \sigma \).

The fact that the reversible component appears to be negligible, removes two of the parameters from consideration of the identification of the CMH parameters. Although, since the Preisach function is not limited to the fourth quadrant, a general identification strategy is not yet available, it is still possible to accurately model the major loop for this medium. We shall illustrate the effect of the remaining parameters and show how they can be identified.

II. EXPERIMENT

The major hysteresis loop of a magnetically uniaxial, RF sputtered 100 nm thick Co-Cr film with 23% Cr, deposited on a Si substrate, was measured using a computer controlled vibrating sample magnetometer. In order to ensure proper nucleation and to obtain a nearly perpendicular anisotropy over the entire thickness of the film, the film was deposited on a Ge seed layer over a SiO₂ layer on the substrate. The major loops in the film plane and perpendicular to the film are shown in Fig.

1. It is seen that the in-plane hysteresis curve is much narrower and is almost completely reversible. On the other hand, the normal hysteresis curve has a negligible reversible component and the knee of the ascending major loop occurs at a negative value of the applied field. Furthermore, it is observed that the ascending major branch is asymmetrical and its susceptibility below the coercivity is greater than that above the coercivity. The measured saturation magnetization is 292 kA/m, and the squareness of the loop is 0.28.

![Graph showing hysteresis loop comparison](image)

**Fig. 1.** Measured normalized magnetization of the Co-Cr perpendicular media along the normal and in the film plane.

III. THE VARIABLE VARIANCE HYSTERESIS MODEL

In this paper, we shall try to explain the nature of only the major loop. The Preisach function shall be described in the operative plane, since it is statistically stable there. In the CMH model the operative interaction field is given by adding the product of the moving parameter, \( \alpha \), and the total magnetization, \( M \), to the interaction field. In the variable variance model, the operative interaction field, \( h_i \), is obtained by dividing the CMH operative interaction field by the standard
deviation in the interaction field, $\sigma_i$. If $\sigma_i$ is a constant, it simply acts as a change of scale. In the variable variance model, $\sigma_i$ is not a constant, but a function of the magnetization. It is assumed that the Preisach function is Gaussian in both the interaction field and the critical field in the operative plane. If we define the operative critical field, $h_c$, by $H/\sigma_c$, then the Preisach function is given by

$$P(h, h_c) = A e^{-\frac{h^2 + (h_c - h)^2}{2\sigma_c^2}},$$

where $A$ is a suitable constant, and $h_c$ is the operative remanent coercivity. Since the critical field of a particle is determined by its physical properties only and not the magnetic state of the system, it is reasonable to expect that $\sigma_c$ is constant. Therefore, in this paper, we shall assume that only $\sigma_i$ varies, and that it is only a function of $M$. We note that in obtaining the major loop only the switching field variance is required, which is given by

$$\sigma^2 = \sigma_i^2 + \sigma_c^2.$$

The particular variation that we shall assume for $\sigma_i$ as a function of the magnetization is given by

$$\sigma_i = \sigma_i(1 - n|M|^k),$$

where $n$ and $k$ are suitably chosen constants. It is noted that if either $n$ or $k$ is zero then the variance is constant, and the model reduces to CMH model. Since the measurements indicated that the reversible component is negligible, we shall assume that it is zero, so in this case the model reduces to the simple moving model. The block diagram for this model is therefore, shown in Fig. 2.

The computed ascending branch of the major loop, assuming that the variance is constant, that is $k = 0$, is shown in Fig. 3. It is seen that as the moving parameter, $\alpha$, becomes more negative, the slope of the branch decreases and the knee moves to the left. Thus, one effect of the negative $\alpha$ is to push the Preisach function outside the fourth quadrant as the medium becomes magnetized. In all these cases, however, the curves maintain their point symmetry about the coercivity, a property of the CMH model when viewed in the operative plane only.

If $k$ is not equal to zero, the symmetry about the coercivity is lost, as shown in Fig. 4. The location of the knee continues to move to the left and the slope of the curve continues to decrease as $\alpha$ becomes more negative. In this case, since $k$ is equal to one, the susceptibility is greater if the applied field is greater than the coercivity than if it is for the corresponding point less than the coercivity.
To illustrate the effect of the exponent $k$ the curves in Fig. 5 were computed. The case where $k = 0$, is the case where the variance is constant. The case where $k = 1$, is the case where the variance in the interaction field varies linearly with the magnetization. When $k = 2$, the variance varies quadratically and so on. It is seen that the larger the value for $k$, the more distortion in the symmetry about the coercivity. Although for nonzero values of $k$ the coercivity is larger than the case when $k = 0$, it is not a strong function of $k$.

**Fig. 4.** Computed ascending major branch for different $\alpha$ when $k = 1$ and $\nu = 1$.

**Fig. 5.** Computed ascending major branch for different values of the exponent, $k$ when $\alpha = -1$ and $\eta = 1$.

For $k = 1$, as $\nu$ is varied, we see in Fig. 6 that the type of asymmetry changes. In particular, for positive values of $\nu$, the second derivative of the magnetization at the coercivity is positive, while for negative values of $\nu$, the second derivative of the magnetization at the coercivity is negative. These observations are useful in fitting the measured curves with this model.

**Fig. 6.** Effect of $\nu$ on the computed ascending branch of the major hysteresis loop, $\alpha = -1$ and $k = 1$.

IV. FITTING THE MAJOR LOOP WITH THE MODEL

The identification of the parameters in the model has not been solved in general; however, for this particular medium a good fit of the major loop data was obtained with the following data: $h_{sat} = 6$, $\sigma_{c} = 100$ Oe, $\sigma_{e} = 50$ Oe, $k = 2$, $\nu = -1.4$, and $\alpha = -2.7$. When $M$ is zero, from (2) and (3), it is seen that $\sigma$ is equal to 112 Oe, thus the coercivity, which is equal to $\sigma h_{sat}$, is equal to 672 Oe. The negative $\nu$ indicates that the variance is larger when the medium is saturated. The resulting simulation is shown by the solid curve in Fig. 7. It is seen that the fit, indicated by the line, with the measured values, indicated by the dots, is very good. This is the more remarkable since the Preisach function in the operative plane is a very smooth and symmetrical Gaussian curve, whereas, the observed susceptibility is very asymmetrical.

V. DISCUSSION

The CMH model is a seven parameter model that can adequately describe longitudinal media, for which it can be shown that the variance is approximately constant. This is not true in the case of thin film Co-Cr perpendicular media, which consists of an essentially single layer of particles. Thus, the particles are surrounded by other particles in essentially two dimensions, rather than three. Therefore, the interaction between any pair of particles is always negative. The resulting moving parameter, unlike for longitudinal media, is negative. This parameter includes the demagnetizing effect of the shape of the medium, since on this scale it is difficult to distinguish the two.
Fig. 7. Comparison of measurements of the ascending major loop of the Co-Cr sample with the variable variance model. The dots indicate the measured values and line is the simulation.

The question of why the variance increases with magnitude of the magnetization in this case and not in the case of the artificial magnetooptic media shall now be addressed. In the case of artificial media, the individual particles were many orders of magnitude larger than the Co-Cr particles. Also, their aspect ratio was completely different; that is, the artificial media consisted of "particles" that were flat and whose thickness was much smaller than their width, while the Co-Cr particles were long and thin columns. Thus, surface roughness plays a much smaller role in the artificial media.

The reversal mechanism is also very different in the two media. In the artificial media a domain reverses by rotation. Consequently they have a quality factor, $Q$, the ratio of the anisotropy field to the demagnetizing field, of several hundred and are very hard magnetically. In Co-Cr, on the other hand, with a $Q$ of approximately 5, reversals will occur by having a wall nucleate at either end of the particle and propagate along the length of the particle, even if the field is reduced. Thus, only the field at the end of the particle is important to the nucleation of a reversal. Furthermore, they are not single domain and in the demagnetized state they break up into many domains, thus, the particles' demagnetizing field is greatly reduced.

The surface field is most variable due to surface roughness at the ends of the particle, since some particles will interact positively and some will interact negatively. This variation is a function of the magnetization and will be smaller in the demagnetized state. When the parameters were chosen to fit the measured data, it was found that $v$ was negative and the slope of the magnetization curve was smaller above the coercivity than it was at the corresponding point below the coercivity.

Although the major loop fit was far better than the measurement accuracy, we are not convinced that this set of parameters is the best set to characterize the medium. No attempt was made to fit minor loop data. It was shown that the height of minor loops is a strong function of the ratio of the interaction field variance to the critical field variance [6]. Since there are many degrees of freedom in this model, another set of parameters might be found that equally well fit the major loop data but have a different ratio of $\sigma / \sigma_c$.

VI. CONCLUSIONS

A model that accurately describes the major hysteresis loop of Co-Cr perpendicular recording medium has been presented. Since this medium has negligible reversible magnetization, a reasonable identification strategy was implemented by studying the effect of each of the parameters on the hysteresis loop. This strategy is not simple and the result was not unique; however, it showed that this model is not unreasonable even though a general identification strategy is still the object of future research.

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REFERENCES