Hysteresis Loops and Transition Shapes During Recording

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***Abstract*—Hysteresis loop shapes corresponding to particular recorded transition shapes are calculated self-consistently. It is found that the closer a ramp function comes to the shape of the transition, the squarer the hysteresis loop that is needed.**

***Index Terms*—Magnetic recording theory, magnetic transition shapes.**

I. Introduction

RECORD theory is now well developed whereby for given hysteresis loop shapes it is possible to calculate the shape of recorded transitions. Sometimes this is a difficult and time consuming process, and it is shown here that much can be learned by starting with a recorded transition shape and working back to find the corresponding hysteresis loop. By illuminating the relationship between hysteresis loop shape and transition shape it is now much easier to chose an appropriate form of a transition for use in simple analytical theories (e.g., [1]) and so avoid a choice which could be inappropriate or contentious.

Hysteresis loops corresponding to three different recorded transitions are calculated in the next section.

II. Theory

Recording is assumed to take place with a wide gap head as shown in Fig. 1 where the longitudinal component of the head field H_x is given by

$$H_x = \frac{H_g}{\pi}\left[\frac{\pi}{2} - \tan^{-1}\left(\frac{x}{y}\right)\right] \tag{1}$$

where H_g is the head gap field. In these calculations this field takes a value of

$$H_g = 2H_c$$

where H_c is the coercivity of the recording medium. The form of H_x is shown in Fig. 2. This field is assumed to create in the medium a transition in the longitudinal component of magnetization of the form

$$M_x = \frac{-2M_r}{\pi}\tan^{-1}\left(\frac{x}{a}\right) \tag{2}$$

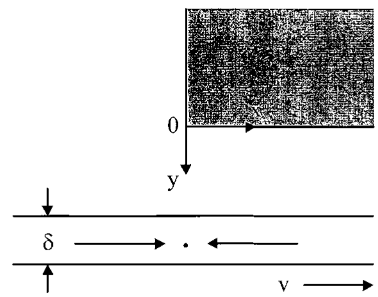

Fig. 1. Head and medium geometry.

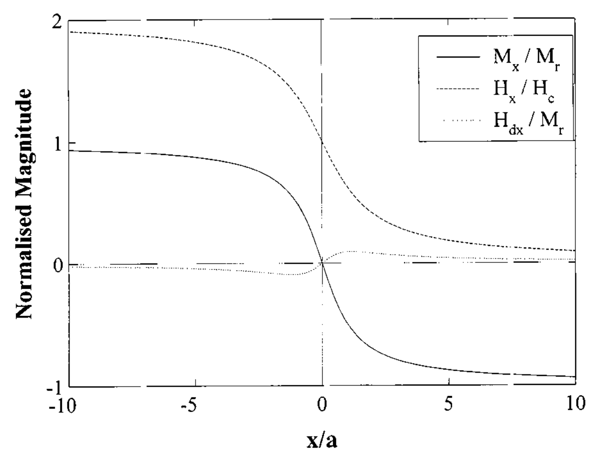

Fig. 2. Recorded magnetization transition, applied head field, and medium demagnetization field. For these calculations $a = 0.1$ µm, $d = 0.05$ µm, $\delta = 30$ nm, and $y = d + \delta/2$.

where M_r is the remanent magnetization and a is the transition width parameter. Fig. 2 shows this transition shape which produces a self-demagnetizing field H_{dx} given by [2], [3]

$$H_{dx} = \frac{2M_r}{\pi}\left[\tan^{-1}\left(\frac{x}{a}\right) - \tan^{-1}\left(\frac{x}{a+\delta/2}\right)\right] \tag{3}$$

where δ is the thickness of the recording medium assumed to be thin. This is also shown in Fig. 2. The total field in the recording medium H_t is given by

$$H_t = H_x + H_{dx}. \tag{4}$$

Substitution from (1) and (3) into (4) and using x determined from the inversion of (2) leads to a relationship between H_t and M_x of the form

$$H_t = \frac{2H_c}{\pi}\left\{\frac{\pi}{2} + \tan^{-1}\left[\frac{a}{y}\tan\left(\frac{\pi M_x}{2M_r}\right)\right]\right\} - M_x + \frac{2M_r}{\pi}\tan^{-1}\left[\frac{a}{a+\delta/2}\tan\left(\frac{\pi M_x}{2M_r}\right)\right]. \tag{5}$$

Before the hysteresis loop can be plotted, the transition width parameter a needs to be determined. This is accomplished by

Manuscript received July 6, 1999; revised October 14, 1999. This work was supported by a Research Grant (GR/L13001) made available by the Engineering and Physical Sciences Research Council.

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Publisher Item Identifier S 0018-9464(00)00471-4.

using the approach of Williams and Comstock [1], i.e., by solving equation

$$\frac{dM_x}{dx} = \chi \frac{dH_t}{dx}, \qquad x = 0 \tag{6}$$

for a. Here χ is the slope of the hysteresis loop at the coercive point $H_t = H_c$. The result, in agreement with [1] and [3], is

$$a = -\left(\frac{\delta}{4} - \frac{M_r y}{2\chi H_c}\right) + \sqrt{\left(\frac{\delta}{4} - \frac{M_r y}{2\chi H_c}\right)^2 + \frac{(1+\chi)}{2\chi} \cdot \frac{M_r \delta y}{H_c}} \tag{7}$$

where χ is given in reduced units as

$$\chi = n\frac{M_r}{H_c}, \qquad n \geq 1. \tag{8}$$

It is noted that in Williams and Comstock [1] the quantity n is replaced by $1/(1 - S^*)$ and therefore χ is related to the hysteresis loop shape. However, that restriction is not applied here.

The transition width in (7) now gives a transition shape which is entirely consistent with the whole of the hysteresis loop and not just the coercive point.

III. Results

In reduced units the hysteresis loop is given by

$$\frac{H_t}{H_c} = \frac{2}{\pi}\left\{\frac{\pi}{2} + \tan^{-1}\left[\frac{a}{y}\tan\left(\frac{\pi M_x}{2M_r}\right)\right]\right\} - \frac{M_x}{M_r} \cdot \frac{M_r}{H_c} + \frac{2M_r}{\pi H_c}\tan^{-1}\left[\frac{a}{a+\delta/2}\tan\left(\frac{\pi M_x}{2M_r}\right)\right]. \tag{9}$$

Fig. 3 shows hysteresis loops calculated using $n = 1$, $n = 5$, and $n = \infty$. Clearly the hysteresis loop is always rounded and it can be concluded that a rectangular hysteresis loop does not give rise to an arctangent shaped transition.

Similar calculations have been carried out for transitions having shapes

$$M_x = M_r \tanh\left(\frac{2x}{\pi a}\right) \tag{10}$$

and

$$M_x = \begin{cases} \dfrac{M_r x}{2c^3}(3c^2 - x^2), & |x| < c \\ M_r \mathrm{sgn}(x), & |x| \geq c \end{cases} \tag{11}$$

where the latter has been referred to as a third order transition (TOP) [4] with transition width parameter c. The hysteresis loops for all three transition shapes are shown in Fig. 4 for $n = \infty$. It is very clear that the slower the magnetization in the transition is in approaching the remanent magnetization the more rounded the hysteresis loop. For a rectangular hysteresis loop the transition shapes proposed by Valstyn and Bond [4] appear to be good approximations.

IV. Discussion and Conclusion

Through simple examples it has been possible to demonstrate the connection between hysteresis loop shapes and the form of the recorded transitions. The sharper the transition, the closer to rectangular is the hysteresis loop. These results are useful guides when choosing approximate forms for recorded transitions for use in simple analytical works.

Without such a convenient assumption of the form and amplitude of the head field the calculations become more complex. However, a similar procedure can be readily followed numerically, and an interactive process could be developed to infer the transition shape for any hysteresis loop.

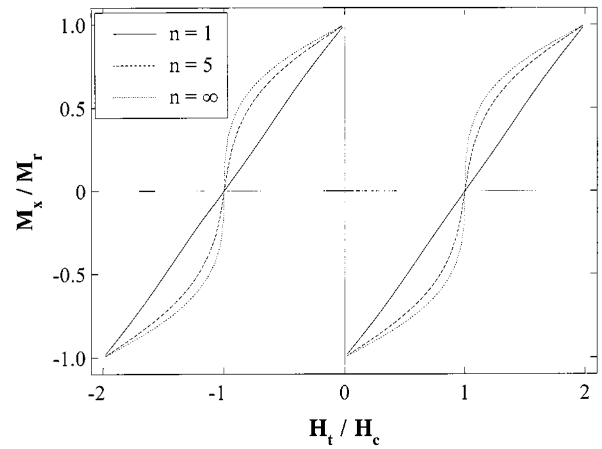

Fig. 3. Hysteresis loops for an arctangent transition for different values of n with $M_r = 300$ kA/m, $H_c = 160$ kA/m, $d = 0.05$ µm, $\delta = 30$ nm, and $y = d + \delta/2$. For $n = 1$, $n = 5$, and $n = \infty$ the corresponding transition width parameters are 84, 44, and 36 nm.

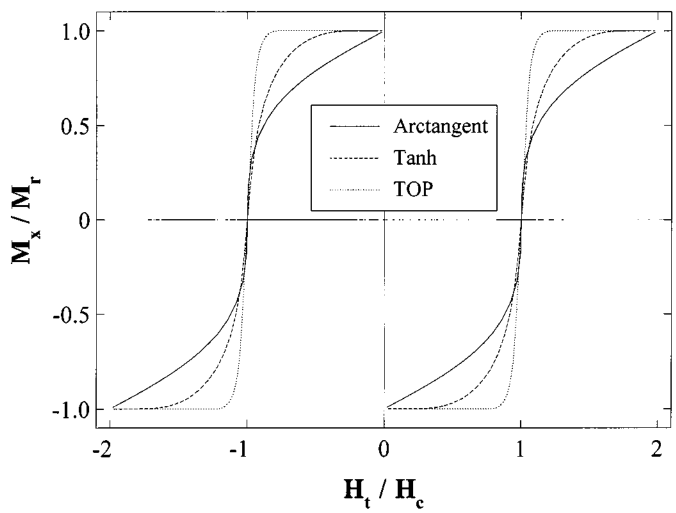

Fig. 4. Hysteresis loops for the arctangent, tanh and third-order transitions for $n = \infty$ with $M_r = 300$ kA/m, $H_c = 160$ kA/m, $d = 0.05$ µm, $\delta = 30$ nm, and $y = d + \delta/2$. The transition width parameters for the arctangent, tanh, and third-order transitions are 36, 35, and $c = 74$ nm.

References

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