

THE SWITCHING CRITERION IN PERPENDICULAR MAGNETIC RECORDING

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Abstract - This paper presents a theoretical analysis of the effect of the "switching criterion", the level at which self-consistency is assumed in calculations on the perpendicular magnetic recording process. It can be proven that in a perpendicular recording configuration with an ideal keeper layer and a recording layer with a rectangular hysteresis loop, the switching criterion in stand-still recording situations is immaterial, because self-consistency is reached at all depth levels simultaneously. If either the keeper layer is absent, or the recording layer's hysteresis loop is sheared, it is shown that the higher the level at which self-consistency is assumed, the sharper the stand-still recorded transitions will be.

INTRODUCTION

In computations of the perpendicular magnetic recording process one often assumes a homogeneous magnetization throughout the depth of the recording layer (y-direction of fig. 1). As a consequence, a fully self-consistent solution, throughout the depth of the recording layer, is not expected and one has to choose a certain level where the self-consistency is thought to dominate the process. In literature, this choice is called the "switching criterion".

There is some dispute about the physical significance of such a criterion [1], which justifies a more detailed study of the effects of a certain choice. As a first step, perpendicular stand-still recording is analysed. It can be proven that for a characteristic configuration of perpendicular recording, namely the pole-keeper configuration and a recording layer material with a rectangular hysteresis loop, the question about the switching criterion is immaterial because, assuming a homogeneous magnetization in the y-direction, self-consistency is reached at all levels at the same time.

The proof relies on the fact that a magnetic field given at a certain level in the layer determines the field at any other level as a consequence of Maxwell's laws.

The relation between fields at different levels in the pole-keeper configuration is given in the literature in direct form [2] or in the Fourier transform [3]. Their equivalence can easily be proven. In terms of the (underlined> Fourier transform the relation reads:

$$H_2 = H_1 \cosh(ky_2) / \cosh(ky_1) \tag{1}$$

with k the wave number and with the subscripts 1 and 2 referring to different levels (see fig. 1). It is of great importance to realise that (1) is not only valid for an applied head field, but for any field generated by sources which are positioned above the highest level (in the y-direction) of consideration.

If the keeper layer is assumed to be at infinity, (1) reduces to:

$$H_2 = H_1 \exp\{|k|(y_2 - y_1)\} \tag{2}$$

This relation shows the well-known exponential spacing-loss factor and is also generally applicable as long as the field sources are positioned above the highest level of consideration [4].

The difference between (1) and (2) is a consequence of the fact that in (2) all field sources are positioned at one side of the levels of consideration (y₁ and y₂), while in (1) the presence of the keeper layer images such sources at the other side as well.

We will use equations (1) and (2) in the description of the stand-still recording process. The properties of the material we use in our model are given in fig. 2 and are equivalent to those used by Lopez [5]. We assume that the material is in an initial state of negative remanence and a positively oriented head field is switched on. In this case, the set of MH-values present in the material is confined to the right-hand rising branch of the hysteresis loop [6].

In the next section we shall show that the simulation of the recording process in a material with a rectangular hysteresis

loop ($\Delta H=0$) with a pole-keeper configuration is not influenced by the choice of the switching criterion. This result seems to be in contradiction with that presented by Lopez and Clark [7]. In subsequent sections we shall handle the situation with $\Delta H \neq 0$ in the pole-keeper configuration and $\Delta H=0$ using a pole without a keeper. It will be shown that placing the switching criterion at the top of the layer (closest to the pole) leads to the sharpest magnetization distributions in these cases.

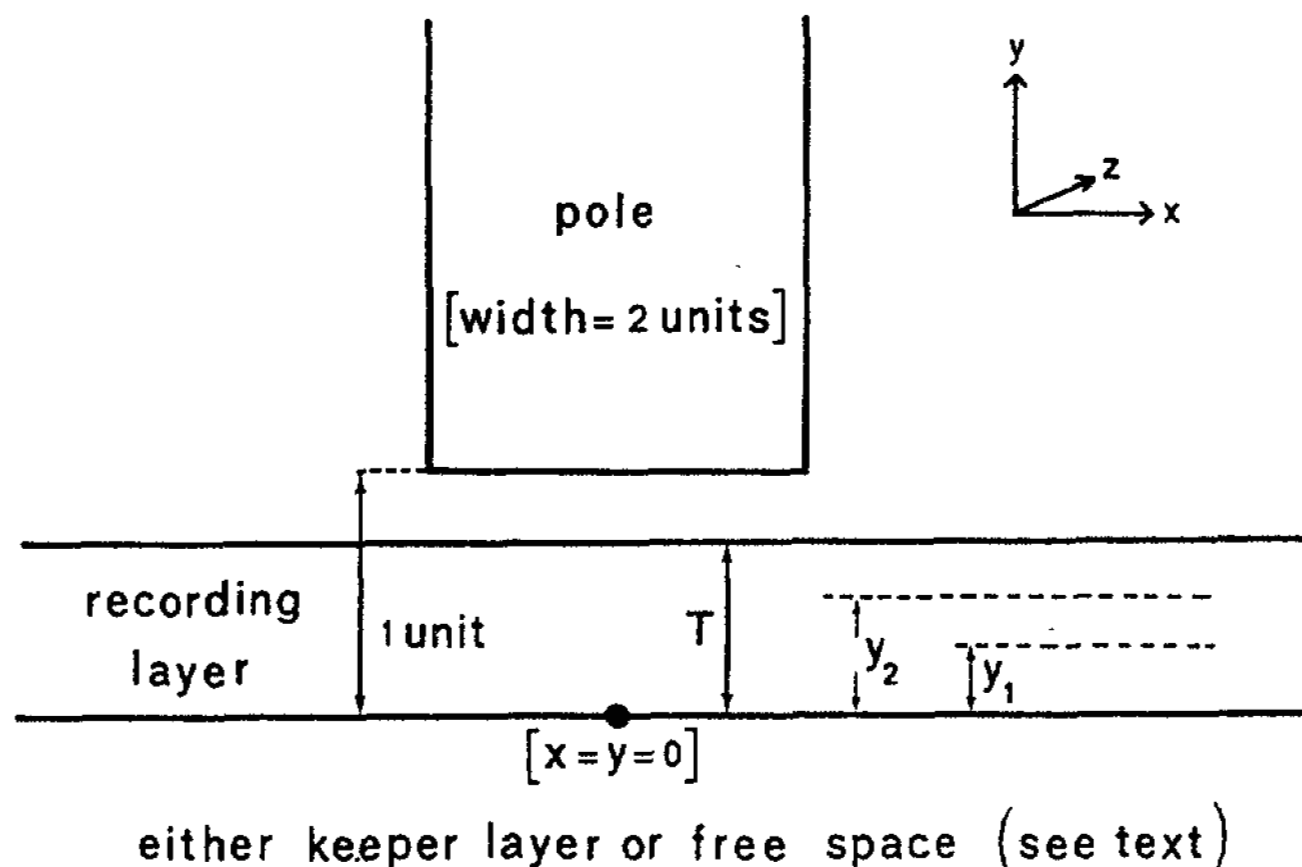


Figure 1. Geometry of the investigated perpendicular recording configuration.

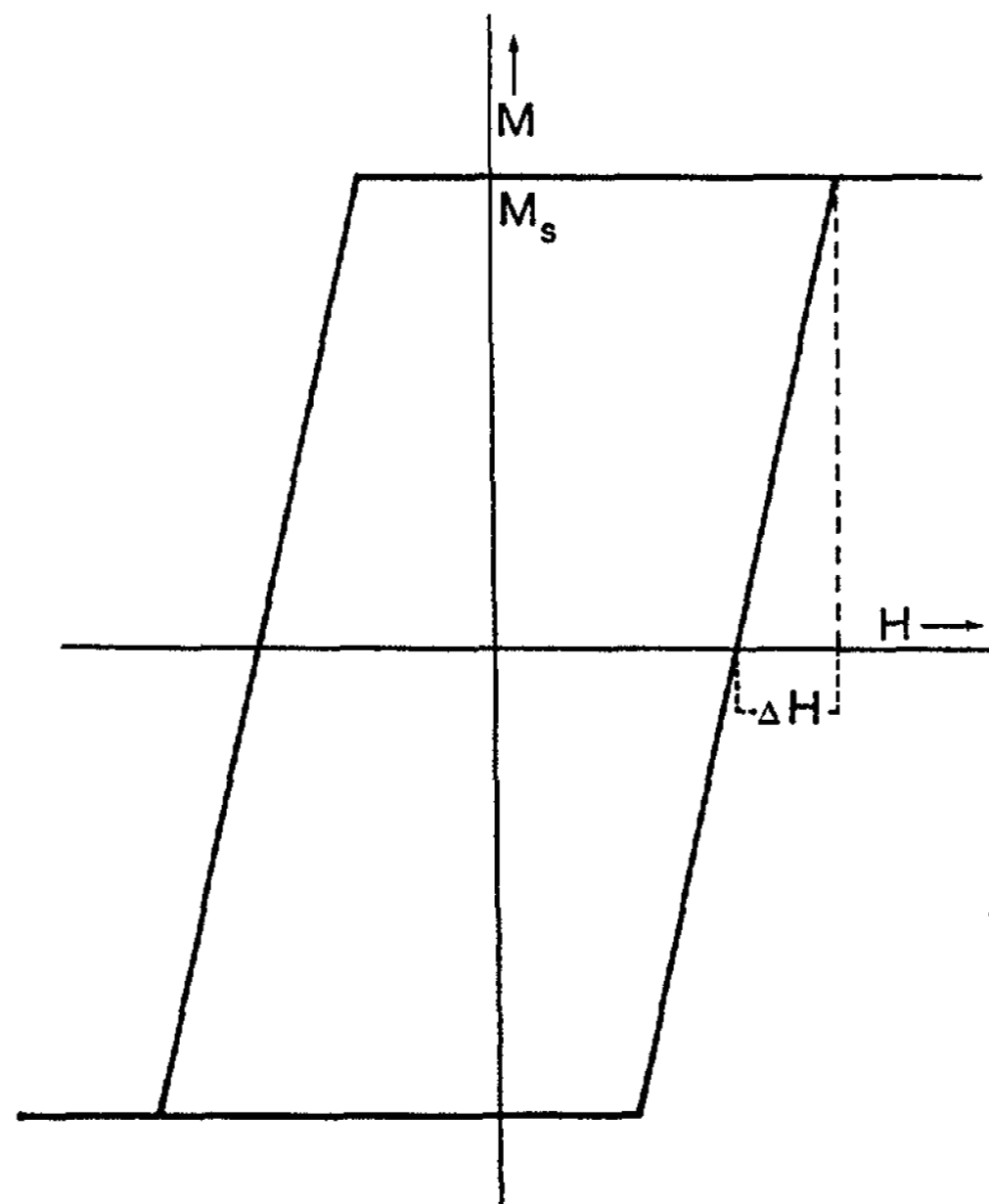


Figure 2. Assumed hysteresis loop of the considered recording layer material.

POLE-KEEPER CONFIGURATION, RECTANGULAR HYSTERESIS LOOP

During recording, two magnetic fields contribute simultaneously to the process. They are the head field and the demagnetizing field generated by the magnetic charges in the recording layer. In our model we assume homogeneity of the magnetization in the y-direction, so the charges are concentrated at the top and bottom surfaces of the layer. An expression in Fourier transform for the demagnetizing field in the recording layer is known from literature [6], reading:

$$H_{dem} = -N_d(k, y) M_k \tag{3}$$

with:

$$N_d = \exp\{-|k|T\} \cdot \cosh(ky) \tag{4}$$

Next, using (1), we can express the applied head field at level y as a function of the head field H_{top} as it is found at the top of the recording layer:

$$H_{appl}(k, y) = H_{top} \cosh(ky) / \cosh(kT) \quad (5)$$

In fig. 3 the field H_{top} is given for the characteristic cases which will be analysed in the computations that follow. The field with a keeper layer present is calculated with the method as proposed by Szczech [2], while the field without keeper layer is approximated by an exact calculation of the longitudinal component of a ring head [8]. This approximation is justified, because our conclusions concerning the switching criterion are factually independent of the shape of H_{top} . Smooth head-field distributions are needed in order to obtain accurate Fourier transforms.

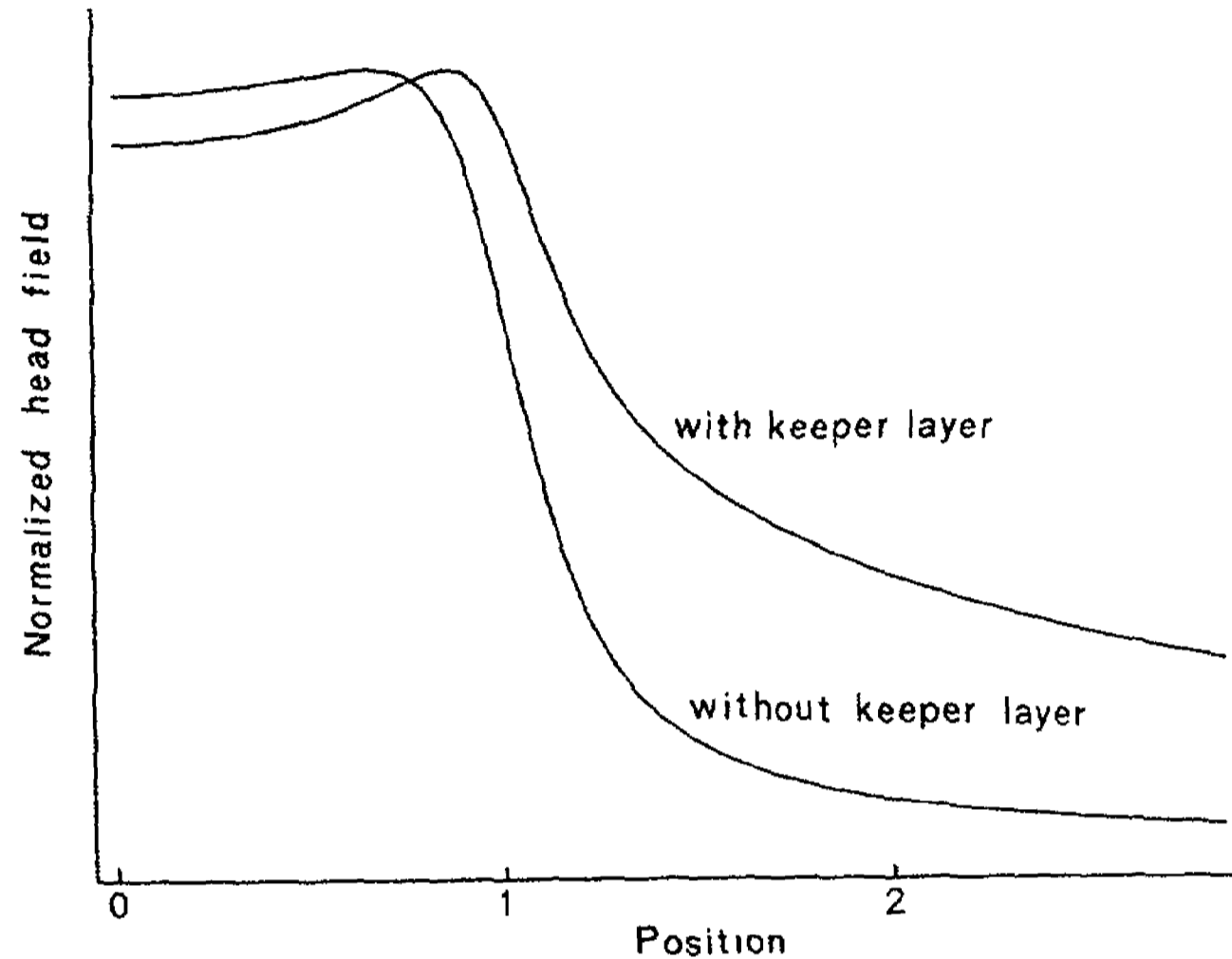


Figure 3. Normalized head fields with and without the presence of a keeper layer ($T = 0.8$ units).

Assuming an initial magnetization in a negative sense and a head field in a positive sense, the rectangular hysteresis loop prescribes:

$$H_{dem} + H_{appl} = H_c \quad (6)$$

So, for $k \neq 0$ we have $H_{dem} = -H_{appl}$ which, together with (3), (4) and (5) leads to the important result:

$$M = H_{top} \exp\{|k|T\} / \cosh(kT) \quad (7)$$

This result, illustrated in fig. 4 for the field shown in fig. 3, is independent of y which proves that self-consistency is reached at all levels at the same time, assuming a

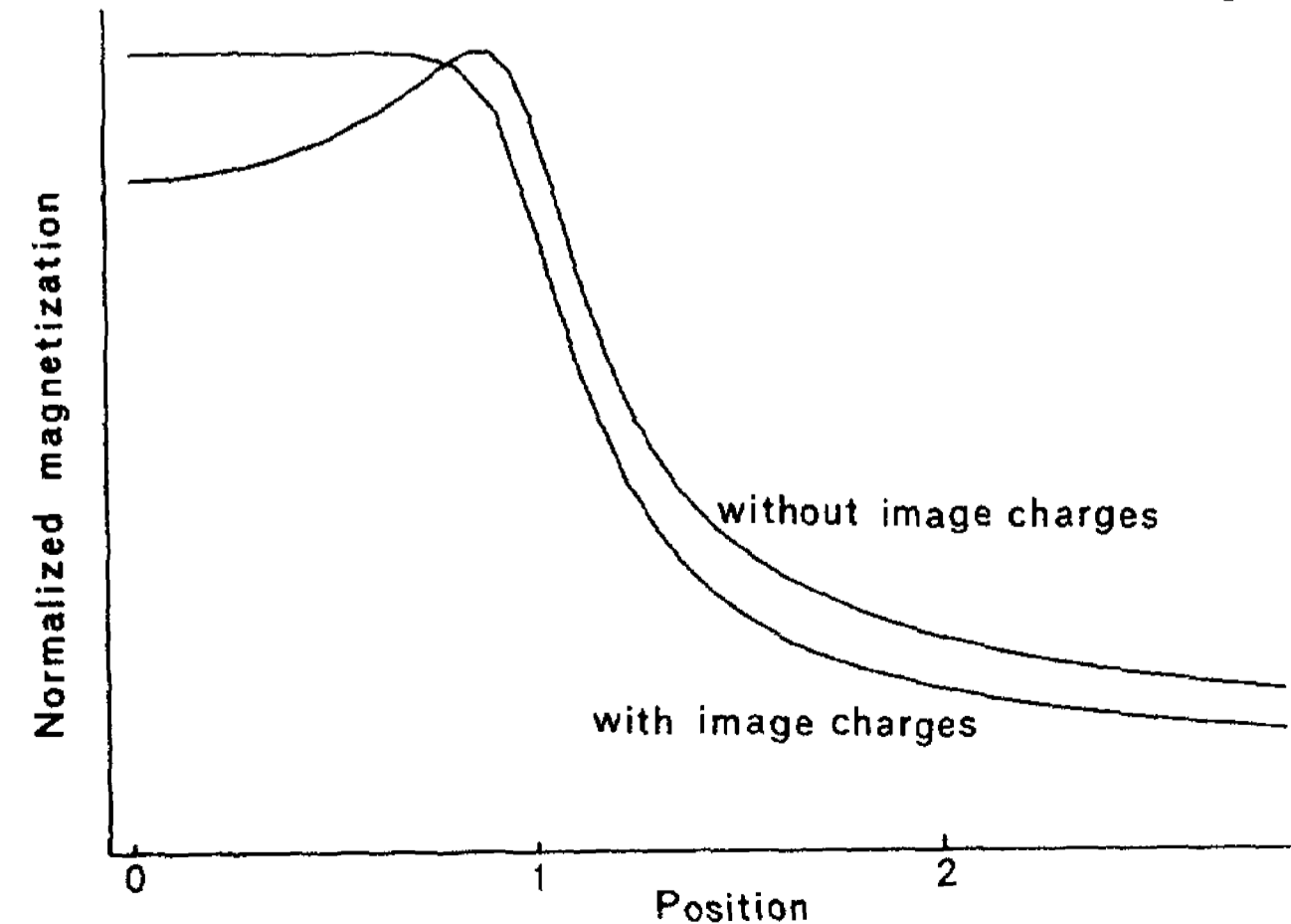


Figure 4. Normalized magnetization distributions with and without the influence of the image-charge distribution in the pole being taken into account ($T = 0.8$ units), both in presence of a keeper layer.

homogeneous magnetization throughout the depth of the recording layer.

The background of this result is that (1) is valid for the applied head field, but at the same time for the demagnetizing field. This is easily checked considering expressions (3) and (4). Hence, the harmonic contents remain "in pace" when descending into the recording layer.

The charges that contribute to the demagnetizing field are partly above the highest level of consideration (considered to be separated by an infinitesimal distance from the top of the recording layer) while the charges at the bottom of the layer are effectively neutralized by the keeper layer. Hence, the requirement for equation (1) to be valid is fulfilled by the demagnetizing field.

We can even go one step further and state that the conclusion about the switching criterion is valid as well if the image charges in the pole are taken into consideration. If we include these charges in the computation of the demagnetizing field, equation (1) remains applicable because the image charges in the pole are again above the top level. It is not possible to demonstrate this analytically, but we have checked it using the computer simulation described by Beusekamp and Fluitman [9]. The resulting magnetization distribution, presented in fig. 4, indeed proved to be independent of the switching criterion, which at the same time can be considered as a strong check of the model's algorithm.

POLE-KEEPER CONFIGURATION, SHEARED HYSTERESIS LOOP

For the pole-keeper configuration and recording on a layer with a sheared hysteresis loop, it can be derived for $k \neq 0$:

$$M = \frac{H_{top} \frac{\cosh(ky)}{\cosh(kT)}}{\frac{\Delta H}{M_s} + e^{-|k|T} \cosh(ky)} \quad (8)$$

The y -dependence is now clearly shown, so that it can be concluded that the homogeneity of the self-consistency is cancelled if the hysteresis loop is not rectangular.

Introducing $g = (T-y)/T$ and rewriting equation (8) in the following form:

$$M = \frac{\frac{H_{top} e^{|k|T}}{\cosh(kT)}}{\frac{2 \Delta H / M_s}{1 + e^{-2|k|T}} * \frac{\cosh(kT)}{\cosh\{(1-g)kT\}} + 1} \quad (9)$$

we can arrive at the following conclusion. The term $\cosh(kT) / \cosh\{(1-g)kT\}$ is a monotonously increasing function of k . The increase becomes stronger as g increases from 0 to 1. This means that the contribution of short wavelength components in M decreases when descending into the layer from the top. Figure 5 clearly demonstrates the effect that switching at the top leads to the sharpest peaks. The influence of $\Delta H / M_s$ is demonstrated in fig. 6, which shows the advantage of a rectangular hysteresis loop.

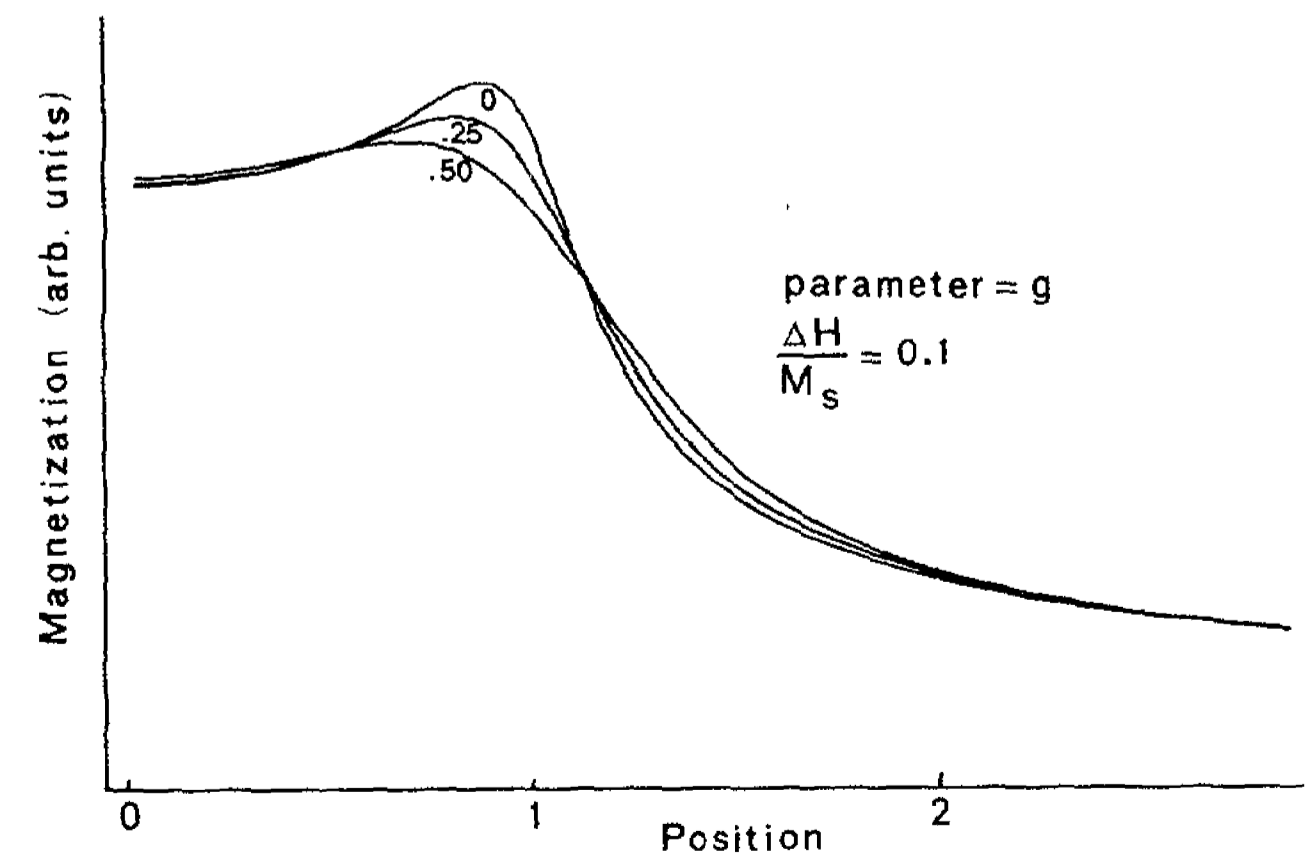


Figure 5. Effect of the level of the switching criterion on the magnetization distribution in the case of a sheared hysteresis loop and an ideal keeper layer.

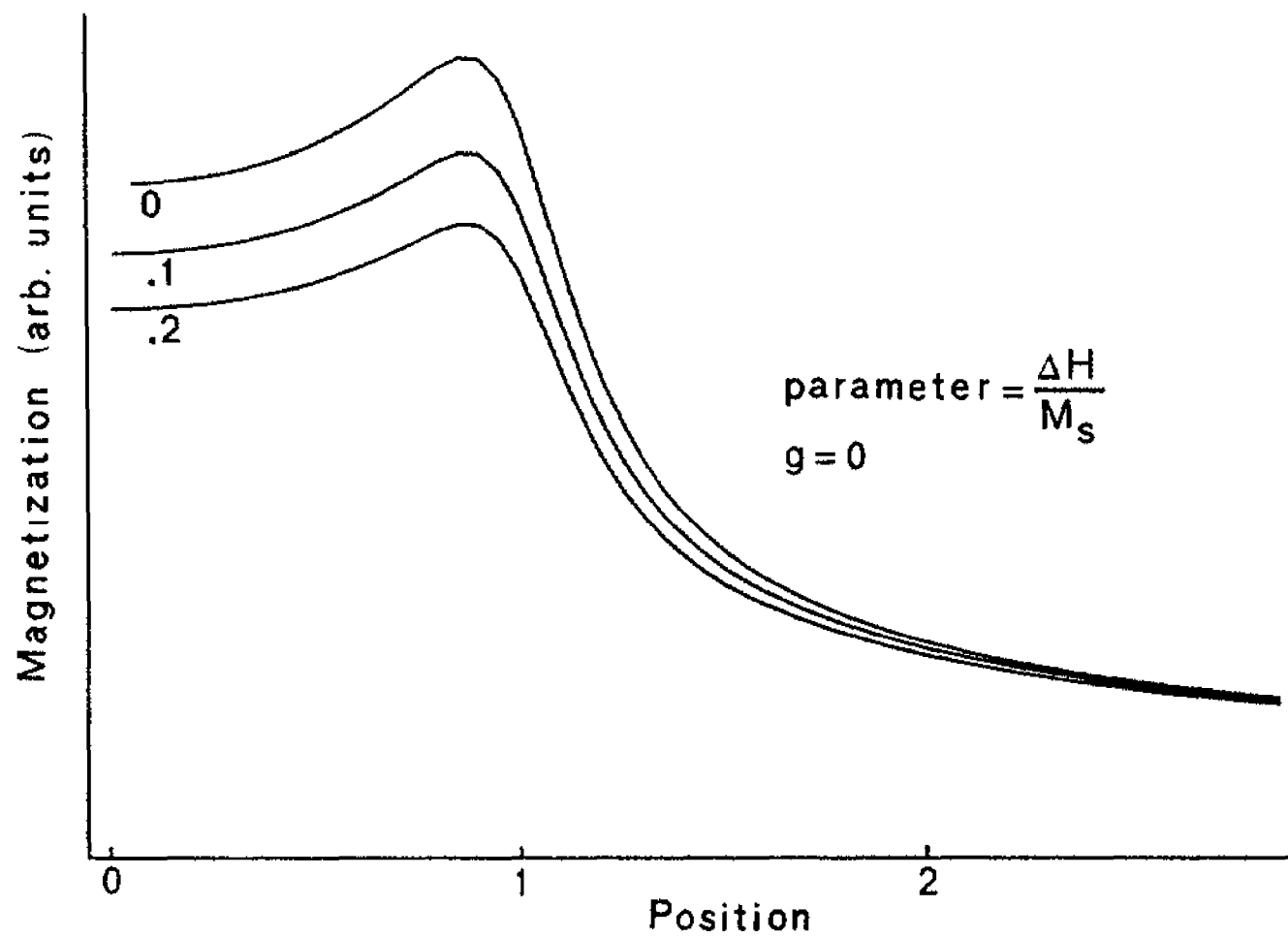


Figure 6. Effect of the shearing of the hysteresis loop on the magnetization distribution in the presence of an ideal keeper layer.

POLE WITHOUT A KEEPER LAYER, RECTANGULAR HYSTERESIS LOOP

Finally, we will treat the case of a pole without a keeper layer. In this case the applied head field behaves as prescribed by equation (2). However, it cannot be expected that the same will be true for the demagnetizing field since this field is the result of charges which are situated at both sides of the level of computation. From (2) it follows:

$$\underline{H}_{\text{appl}}(k, y) = \underline{H}_{\text{top}} \exp\{-|k|(T-y)\} \quad (10)$$

The expression for the demagnetizing factor in this case reads:

$$\underline{N}_d = \exp\{-|k|(T/2)\} \cosh\{k(T/2-y)\} \quad (11)$$

(3), (6), (10) and (11) now lead to:

$$\underline{M} = 2\underline{H}_{\text{top}} / [1 + \exp\{-|k|(2y-T)\}] \quad (12)$$

It is seen that in this case the switching criterion is also of influence.

Again introducing $g=(T-y)/T$, we can rewrite (12) into:

$$\underline{M} = 2\underline{H}_{\text{top}} / [1 + \exp\{-|k|T(1-2g)\}] \quad (13)$$

It is seen that if $g < 1/2$, which means that we restrict ourselves to the upper half of the recording layer, the exponent in the denominator is negative and decreases for increasing $|k|$. The decrease will be less however if we descend into the layer from the top, leading to less "sharpening" of \underline{M} . This result is illustrated in fig. 7. Note that at the middle of the layer we have $\underline{M} = \underline{H}_{\text{top}}$, a result already noted by Middleton et al. [10].

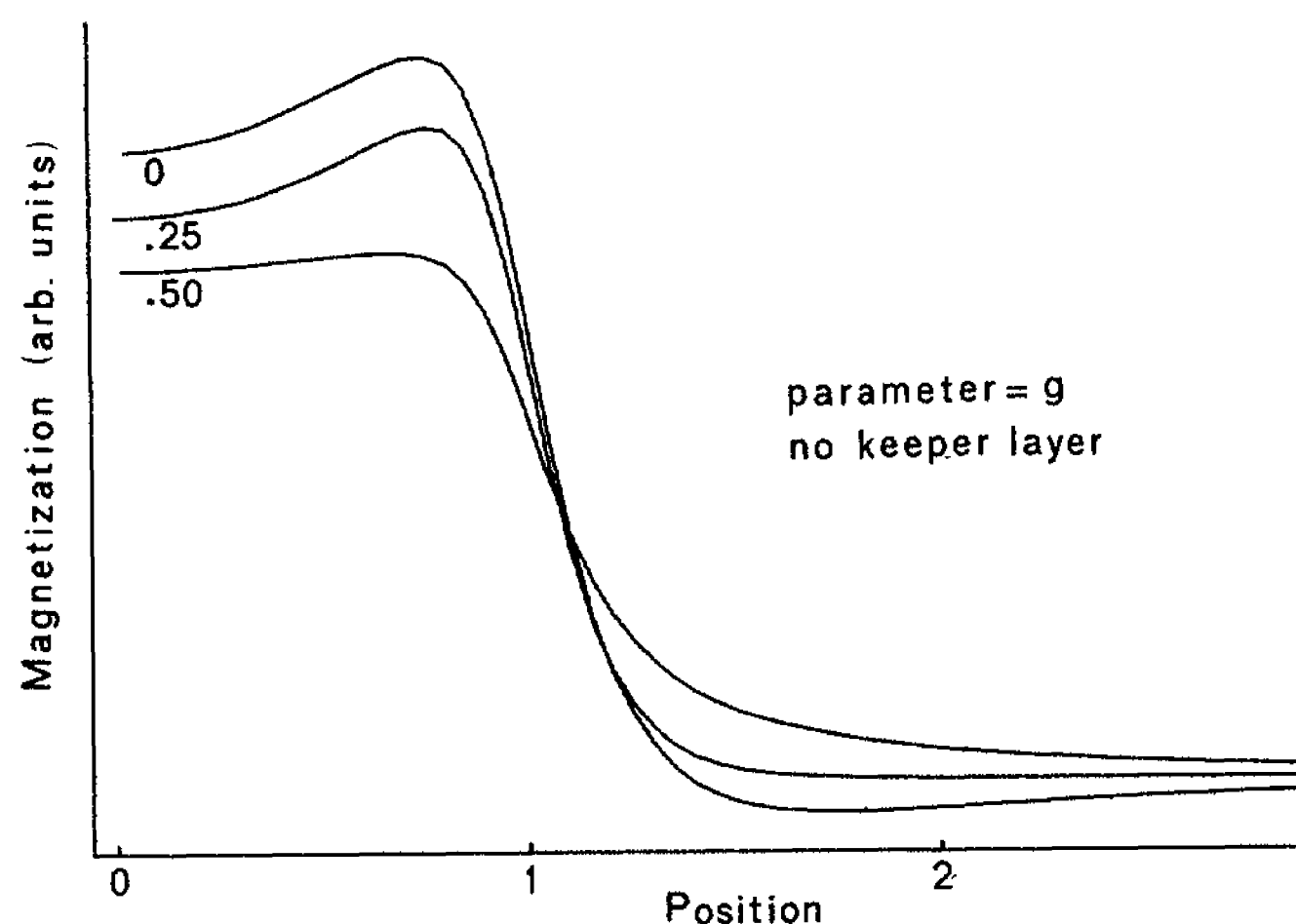


Figure 7. Effect of the level of the switching criterion on the magnetization distribution in the case of a rectangular hysteresis loop and with no keeper layer present.

CONCLUSIONS

It has been shown that the choice of a switching criterion is immaterial in the case of a pole-keeper configuration and stand-still recording on a material with a rectangular hysteresis loop. The proof relies on major principles concerning the structure of magnetic fields in general and not on the particular structure of some specific field. It should be noted that our conclusion is valid for any geometry of the head parts that are situated above the top of the recording layer. As long as the ideal keeper layer is present the proof will run correctly. This means that deviations from an ideal geometry of the pole piece or the recording layer surface, which can be expected in practice, are of no influence. When deviations occur with respect to rectangularity of the hysteresis curve for the recording layer material or the ideality of the keeper layer, we can expect from our results that switching at the top of the recording layer will lead to sharper transitions.

Equation (6) is an essential part of the proof which means that the validity of our conclusions is limited to stand-still recording. The evolution of the transitions while removing the head and switching the head field is a subject of further research. A relaxation process will occur in a way which will probably depend on bit-density, the value of H_C and the level of the switching criterion. It is not clear in advance at what level the best "readable" transitions will be formed.

We have computed the results presented in the figures with the help of a standard Fast Fourier Transform program. The field of computation has been taken 25 times as wide as the width of the pole. The accuracy of the results obtained this way is limited by this procedure, but sufficiently high to demonstrate the conclusions we arrived at.

REFERENCES

- 1) J.C. Mallinson. "A Theoretical and Experimental Comparison of the Longitudinal and Vertical Modes of Magnetic Recording." *I.E.E.E. Trans. on Magn.*, Vol. MAG-20, No. 3, pp. 461-7, May 1984.
- 2) T.J. Szczech, M. Steinback, M. Jodeit, Jr. "Equations for the Field Components of a Perpendicular Magnetic Head." *I.E.E.E. Trans. on Magn.*, Vol. MAG-18, No. 1, pp. 229-32, January 1982.
- 3) O. Lopez. "Reproducing Vertically Recorded Information-Double Layer Media." *I.E.E.E. Trans. on Magn.*, Vol. MAG-19, No. 5, pp. 1614-6, September 1983.
- 4) J.C. Mallinson. "On the Properties of Two-Dimensional Dipoles and Magnetized Bodies." *I.E.E.E. Trans. on Magn.*, Vol. MAG-17, No. 5, pp. 2453-60, September 1981.
- 5) O. Lopez. "Analytic Calculation of Write Induced Separation Losses." *I.E.E.E. Trans. on Magn.*, Vol. MAG-20, No. 5, pp. 715-7, September 1984.
- 6) T. Wielinga, J.H.J. Fluitman, J.C. Lodder. "Perpendicular Stand-Still Recording in CoCr-Films." *I.E.E.E. Trans. on Magn.*, Vol. MAG-19, No. 2, pp. 94-104, March 1983.
- 7) O. Lopez, D.A. Clark. "On the Perpendicular Recording Process." *J. of Appl. Phys.*, Vol. 57, No. 1, pp. 3943-5, April 1985.
- 8) S. Iwasaki, Y. Nakamura, H. Muracka. "Wavelength Response of Perpendicular Magnetic Recording." *I.E.E.E. Trans. on Magn.*, Vol. MAG-17, No. 6, pp. 2535-7, November 1981.
- 9) M.F. Beusekamp, J.H. Fluitman. "Significance of Image-Charge Fields on the Write Performance of a Pole-Keeper Head." *I.E.E.E. Trans. on Magn.*, Vol. MAG-21, No. 5, pp. 1414-6, September 1985.
- 10) B.K. Middleton, C.D. Wright. "The Perpendicular Recording Process." *I.E.E.E. Trans. on Magn.*, Vol. MAG-20, No. 2, pp. 458-9, March 1984.