THE REACTION OF PERPENDICULAR RECORDING MEDIA TO THE HEADS

Jianglin ZHANG and Xiang-jun FENG

Huazhong University of Science and Technology
 Wuhan, Hubei, P. R. China

Abstract --- This paper made an investigation to the interaction between the double-layer perpendicular recording media to an arbitrary head. It was showed that generally speaking the interaction is determined not only by the parameters of head-medium system, but also by the history of magnetization. Under certain conditions the existence of the recording medium will equivalently move the underlayer up to the top surface of the medium and thus greatly improves the field distribution and the written magnetization for the single pole heads. It was also discussed qualitatively that the effect of the interaction might be able to become even better during the actual recording process.

INTRODUCTION

Recently perpendicular magnetic recording with a single pole head and double-layer media has shown its potential to realize ultra high bit density. When it comes to talking about the superiority of the recording mode, theories have already paid attention to the interaction between the head and media during the writing process [1]. This paper dealt with the interaction in a different way.

THEORY

General Description

During the write process, the head field will induce magnetization in the recording medium. The induced magnetization will then produce spatial field. Since the spatial field directly acts on the head core, it will make a change in the head field (which is meant by the spatial field emanating from the head and its image during the actual writing process.) New head field will induce new magnetization, and the new magnetization will again produce new head field. The process will proceed, provided that magnetic saturation does not occur in the head and media. That is what we called the interaction [2]. The interaction will certainly improve the head field and the written magnetization for the system of single pole head and double layer media, since that whether the action or the

reaction provides an extra driving field. It is therefore very interesting to explore the final effect of such an interaction. The structure and the coordinate was shown in figure 1.

Figure 1. The Double Layer Media and the Head.

For $\delta \leq y < s$ (where $S = \delta + d$), the controlling equations are as follows

$$\nabla^2 \phi(x, y) = 0 \quad (1)$$

$$\phi(x, \delta) = U_0(x) \quad (2)$$

$$\frac{\partial}{\partial y} \phi(x, s) = -f(x) \quad (3)$$

where $\phi(x, y)$ is the magnetic potential function, $U_0(x)$ is the potential distribution on the top surface of the recording medium,

and $f(x)$ is the normal component of the field on the "head plane" [3]. Fourier transforming equations (1), (2) and (3) vs. x

$$\frac{d^2 \Phi(K, y)}{dy^2} - K^2 \Phi(K, y) = 0 \quad (4)$$

$$\Phi(K, \delta) = U_0(K) \quad (5)$$

$$\frac{d\Phi(K, s)}{dy} = -F(K) \quad (6)$$

where $\Phi(K, y)$, $U_0(K)$ and $F(K)$ are respectively the harmonic distributions of $\phi(x, y)$, $U_0(x)$ and $f(x)$. $\Phi(K, y)$ may then be obtained

$$\begin{aligned} \Phi(K, y) = & -\frac{F(K)}{K} \cdot \frac{\sinh[|K|(y - \delta)]}{\cosh(|K|d)} \\ & + U_0(K) \cdot \frac{\cosh[|K|(s - y)]}{\cosh(|K|d)} \end{aligned} \quad (7)$$

From equation (7) the harmonic distribution of the total field $H_y(x, y)$ ($\delta \leq y \leq s$) can be expressed as

$$\begin{aligned} H_y(K, y) = & F(K) \cdot \frac{\cosh[|K|(y - \delta)]}{\cosh(|K|d)} \\ & + U_0(K) \cdot K \cdot \frac{\sinh[|K|(s - y)]}{\cosh(|K|d)} \end{aligned} \quad (8)$$

From equation (8) the magnetization on the top surface of the recording medium can also be given formally

$$\begin{aligned} M_y(K, \delta) = & \frac{1}{4\pi} [F(K)/\cosh(|K|d) + U_0(K) \\ & \cdot K \cdot \tanh(|K|d)] - \frac{1}{4\pi} H_0(K) \end{aligned} \quad (9)$$

where $H_0(K)$ is the harmonic distribution of the total field on the inner side of the top surface of the recording medium. Since the underlayer possesses a constant potential $U_0(K)$ can be expressed as

$$U_0(K) = \delta \cdot \bar{H}_{ym}(K) \quad (10)$$

where $\bar{H}_{ym}(K)$ is the average integral value of $H_{ym}(K, y)$ ($0 \leq y \leq \delta$) which is the harmonic distribution of the total field in the recording medium. From equations (8) - (10) one may see that generally speaking the interaction not only depends on the parameters of the head and media but also on the history of magnetization which is a factor determining $U_0(x)$. Let us consider two special cases.

(1) $U_0(x)$ remains a constant C . In this case, the total field $H_y(x, y)$ ($\delta \leq y \leq s$) is a "keepered-head field" and the "keeper" is the top surface of the recording medium. The case describes the situation that will be studied in detail in the following discussion.

(2) $U_0(x)$ remains a constant C_1 for $|x| \leq \frac{T_m}{2}$ and is not larger than C_1 for $|x| > \frac{T_m}{2}$, where T_m is the main pole thickness of the single pole head. When the write current is large enough the case may broadly simulate the actual writing process of a single bit in a medium with an initial magnetization which is not uniform. If C_1 is the same as C in case (1) and the ratio of T_m/d is very large (say $T_m/d = 10$) the total field distribution $H_y(x, y)$ ($\delta \leq y \leq s$) might be better than that in case (1) since the magnetic leakage from the two sides of the head main pole directly to the top surface of the recording medium contributes less normal component for $|x| > \frac{T_m}{2}$ and the total field is the same as that in case (1) for $|x| < \frac{T_m}{2}$. The qualitative comparison made us believe that the effect of the interaction in case (1) is not best. Therefore the discussion about the feature in case (1) is meaningful. Such a logic was initiated under the strong influence of the newborn philosophy of pansystems methodology [4].

An Interesting Case

In this section we discussed the above-mentioned case (1) which will occur under the following assumptions frequently appearing in papers [5].

(1) The perpendicular recording medium is of an ideal rectangular hysteresis loop.

(2) The magnetization only possesses a normal component which does not change in the direction of Y -axis.

(3) The reversible permeability of the underlayer is infinite and that of the recording medium is one.

(4) The magnetic saturation does not occur during the writing process.

(5) The residual magnetization initially lies in the state described by the point $(-M_0, H_C)$ of the hysteresis loop, where H_C is the coercive force.

When a driving field is forced to the recording medium against the direction of the initial magnetization the total field will be equal to H_C every where in the re-

cording medium according to the assumptions (1) and (5).

$$H_h(x, y) + H_{dy}(x, y) = H_c, \text{ for } 0 \leq y \leq \delta \quad (11)$$

where $H_h(x, y)$ is the head field and $H_{dy}(x, y)$ is the demagnetizing field. According to the coordinate system in figure 1 and taking into consideration the image caused by the underlayer

$$H_{dy}(x, y) = 2 \int_{-\infty}^{\infty} M_Y(x') \cdot \frac{(y - \delta)}{(x - x')^2 + (y - \delta)^2} dx' - 2 \int_{-\infty}^{\infty} M_Y(x') \cdot \frac{(y + \delta)}{(x - x')^2 + (y + \delta)^2} dx', \text{ for } 0 \leq y \leq \delta \quad (12)$$

Fourier transforming equations (11) and (12) vs. x

$$H_h(K, y) + H_{dy}(K, y) = 2\pi \delta^*(K) \cdot H_c, \text{ for } 0 \leq y \leq \delta \quad (13)$$

where $\delta^*(K)$ is the Dirac function and

$$H_{dy}(K, y) = -2\pi M_Y(K) [e^{-|K|(\delta - y)} + e^{-|K|(\delta + y)}] \quad (14)$$

From equations (13) and (14)

$$M_Y(K) = M_1(K) + \tilde{M}_Y(K) \quad (15)$$

$$\text{where } M_1(K) = \frac{-H_c \cdot \delta^*(K)}{[e^{-|K|(\delta - y)} + e^{-|K|(\delta + y)}]} \quad (16)$$

$$\text{and } \tilde{M}_Y(K) = \frac{H_h(K, y)}{2\pi [e^{-|K|(\delta - y)} + e^{-|K|(\delta + y)}]} \quad (16)$$

It is easily known from Wallace rule [6] that

$$H_h(K, y) = e^{-|K|(s - y)} \cdot F_1(K) + e^{-|K|(s + y)} \cdot F_1(K) \quad (17)$$

where $F_1(K)$ is the harmonic distribution on the head plane of the field emanating from the main pole itself. Therefore

$$\tilde{M}_Y(K) = \frac{1}{2\pi} e^{-|K|d} \cdot F_1(K) \quad (18)$$

We then have

$$M_1(x) = -\frac{H_c}{4\pi} \quad (19)$$

$$\text{and } \tilde{M}_Y(x) = \frac{1}{2\pi} H_r(x, \delta) \quad (20)$$

where $M_1(x)$ and $\tilde{M}_Y(x)$ are the spatial distributions respectively corresponding to $M_1(K)$ and $\tilde{M}_Y(K)$, and $H_r(x, \delta)$ is the distribution on the top surface of the recording medium of the field emanating from real head only. Equation (20) may also be derived from the general equation (9). From equation (20) it was known that the variable part $\tilde{M}_Y(x)$ of the magnetization $M_Y(x)$ always follows the field $H_r(x, \delta)$ emanating from the real head itself. The spatial field produced by $M_Y(x)$ can then be found.

$$H_{exy}(x, y) = 2 \int_{-\infty}^{\infty} \tilde{M}_Y(x') \cdot \frac{(y - \delta)}{(x - x')^2 + (y - \delta)^2} dx' - 2 \int_{-\infty}^{\infty} \tilde{M}_Y(x') \cdot \frac{(y + \delta)}{(x - x')^2 + (y + \delta)^2} dx', \text{ for } y \geq \delta \quad (21)$$

Fourier transforming (21) Vs. x

$$H_{exy}(K, y) = 2\pi \tilde{M}_Y(K) [e^{-|K|(y - \delta)} - e^{-|K|(y + \delta)}] \quad (22)$$

From equations (18) and (22)

$$H_{exy}(K, y) = F_1(K) e^{-|K|[y - (\delta - d)]} - F_1(K) e^{-|K|[y + s]} \quad (23)$$

$$\text{or } H_{exy}(K, y) + H_i(K, y) = H_{ieff}(K, y) \quad (24)$$

where $H_i(K, y)$ is the harmonic distribution of the field emanating from the image head produced by the underlayer and $H_{ieff}(K, y)$ is that of the field emanating from the effective "image head" only $2d$ away from the real head.

$$H_i(K, y) = F_1(K) e^{-|K|[y + s]} \quad (25)$$

$$\text{and } H_{ieff}(K, y) = F_1(K) e^{-|K|[y - (\delta - d)]} \quad (26)$$

Inversely Fourier transforming (24)

$$H_{exy}(x, y) + H_i(x, y) = H_{ieff}(x, y) \quad (27)$$

Equation (27) seemed a little novel which says that the spatial field from the recording medium plus that from the image head will equal to the spatial field from an effective "image head" which is only $2d$ away

from the real head. In other words the existence of the recording medium equivalently moves the underlayer up to the top surface of the recording medium in terms of the extent of the interaction. Therefore the write head efficiency will be raised and the written magnetization will be improved. The meaning of equation (27) was explained clearly in figure 2. In the following discussion the effect of the reaction on the

Figure 2. The Effect of the Reaction of Double Layer Media to the Head.

write head efficiency was discussed. For the "thick pole head" [7] the relation between the "keepered-head field" deep in the gap and the magnetic motive force NI can be expressed.

$$NI = H_y(x, \delta) \cdot d + H_c \quad (28)$$

where $H_y(x, \delta)$ is the head field on the "keeper" (the top surface of the recording medium) and deep in the gap between the pole and the recording medium. We have

$$H_y(x, \delta) = 2H_r(x, \delta) \quad (29)$$

where $H_r(x, \delta)$ only emanates from the real head. As has been seen that $H_r(x, \delta)$ and $H_y(x, \delta)$ are determined by the real head and the "effective image head" which is only $2d$ away from the real head. From equations (28) - (29)

$$H_r(x, \delta) / NI_{\text{eff}} = 1/2d \quad (30)$$

where NI_{eff} is the effective magnetic motive force to induce new magnetization

$$NI_{\text{eff}} = NI - H_c \cdot \delta \quad (31)$$

From equations (20) and (30) another useful expression was obtained

$$4\pi \tilde{M}(x, \delta) / NI_{\text{eff}} = 1/d \quad (32)$$

Equations (30) and (32) indicate that owing to the reaction of the double layer media to the head, the head field $H_r(x, \delta)$ and the induced magnetization $\tilde{M}(x, \delta)$ produced by unit effective MMF will be sharply increased as the head-medium spacing d decreases. The results was shown in Table 1. In this table the data $d = 0.15 \mu\text{m}$ was the head-medium spacing of the new type of floppy disk

Table 1. The Effect of the Interaction On the Efficiency of the "Thick Pole Head."

$d(\mu\text{m})$	$\frac{H_r(x, \delta)}{NI_{\text{eff}}}$ (oe/A·T)	$\frac{4 \tilde{M}(x, \delta)}{NI_{\text{eff}}}$ [(emu/cc)/A·T]
0.05	10^5	2×10^5
0.15	3.33×10^4	6.67×10^4
0.254	1.97×10^4	3.94×10^4

drive using the know-how of SSR (Stretched Surface Recording) and developed by 3M Cooperation [8], and the data $d = 0.254 \mu\text{m}$ was that of another kind of newborn floppy disk drive using the so-called "Bernoulli Technology" and manufactured by Iomega Corporation [9]. For the traditional single pole head, the thickness T_m of the main pole will be much smaller than the length L . The efficiency can then be described by the "effective permeability" μ_m .

$$\mu_m \triangleq \frac{H_{sp_0}}{H_0} \quad (33)$$

where H_0 is the driving field at the center of the main pole tip produced by the write current and H_{sp_0} is the field of the real head at the center emanating from the real head only. Since the interaction is a positive feedback process to make the H_{sp_0} continuously strengthened, μ_m will become larger than its initial value μ_m^{old} which is

determined by the driving field H_0 and the real head.

$$\mu_m^{\text{old}} = \frac{4\pi - N_D}{N_D} \frac{K_m N_D}{1 + K_m N_D} \quad (34)$$

where N_D is the local demagnetizing factor of the main pole tip and K_m is the intrinsic susceptibility of the film of main pole. The final value μ_m^{new} of the effective permeability was found.

$$\mu_m^{\text{new}} = \mu_m^{\text{old}} \left[1 + \frac{P}{1 - P} \right], \text{ for } P < 1 \quad (35)$$

$$\text{where } P \approx \frac{2}{\pi} \arctan \left(\frac{T_m}{4d} \right) \cdot \mu_m^{\text{old}} \quad (36)$$

Therefore μ_m^{new} is $\frac{P}{1 - P}$ times larger than μ_m^{old} . Table 2 showed the effect in detail.

Table 2. The Effect of the Interaction on the Efficiency of the Ordinary SPT Heads.

N_D	$\frac{T_m}{d}$	K_m	$\frac{P}{1 - P}$
2π	25	100	8.76
2π	20	100	6.87
2π	10	100	3.11
2π	7	100	2.02
2π	5	100	1.32

Sample Calculation for the Interesting Case

The sample calculation was carried out by a fully automatic 2D FEM software pack and was for a single pole head in the said case (1). To exhibit the effect of the interaction, we examine the field distribution on the top surface of the recording medium for two cases. One is the case when the recording layer is present and the other is that when the recording layer is absent. In the calculation the magnetic potential differences between the head and the underlayer (case 1) was assumed to be the same as that between the head and the "effective keeper" that is the top surface of the recording medium (case 2). The parameters were as follows. $L/T_m = 100$ (where L is the length of the main pole) $\delta/T_m = 0.5$, and $d/T_m = 0.1$. The results were normalized by H_a which was the average value of the normal component of the field in the area

Figure 3. The Field Distributions on the Top Surface of the Recording Layer.

Case 1 — The Recording Layer Is Absent

Case 2 — The Recording Layer Is Present

below the main pole tip and above the underlayer when the recording layer was absent. From figure 3 one can see that the interaction will also improve the distribution of the field and thus improve that of the written magnetization.

CONCLUSION AND DISCUSSIONS

1. The reaction of the double layer media to the single pole head will remarkably improve the written magnetization.
2. The normalized variable part of the written magnetization in the recording medium with rectangular hysteresis loop can be determined by a "keepered-head field" with the top surface of the recording medium as "keeper" and then be independent of the medium thickness δ under certain conditions.

REFERENCES

- [1] M. F. Beusekamp and Jan H. Fluitman, IEEE Trans. on Magn., Vol. MAG-21, No. 5, pp. 1414-6, Sept. (1985).
- [2] Xiang-jun Feng, Master Thesis of Huazhong University of Science and Technology,

Nov. (1986).

[3] Xiang-jun Feng, PMRC'89, Paper No. 30p-21, Aug. (1989).

[4] Wu Xuemou, Pansystems Methodology, Science Exploration, 1, 2, 4 (1982), 1, 4, (1983), 1, 4 (1984), 1 (1985), 3 (1986).

[5] T. Wielinga et al, IEEE Trans. on Magn., Vol. MAG-19, No. 2, pp. 94-104, Mar.(1983).

[6] V. B. Minuhin, IEEE Trans. on Magn., Vol. MAG-21, No. 1, pp. 28-35, Jan. (1985).

[7] A. Ohtsubo and Y. Satoh, IEEE Trans. on Magn., Vol. MAG-18, No. 6, pp.1173-5, Nov. (1982).

[8] J. K. Knudsen, IEEE Trans. on Magn., Vol. MAG-21, No. 6, pp. 2588-2591, Nov., (1985).

[9] Tom Manuel, Electronics, Vol. 60, No. 19, pp. 114, Sept. (1987).