THEORETICAL ANALYSES OF READBACK WAVEFORM OF ISOLATED PERPENDICULAR MAGNETIZATION FOR DOUBLE—LAYER—MEDIUM WITH RING—TYPE HEAD

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Abstracts — — — There are two possible arrangements of the ring—type head and medium in a perpendicular recording system: (1) A ring—type head and a single—layer—medium. (2) A ring—type head and a double—layer—medium. The arrangement (2) is considered here. The readback process of isolated perpendicular magnetization for double—layer—medium with a ring—type head is discussed by reciprocity theorem. In the calculation process, the effect of self—demagnetizing field in medium is neglected. The interaction between the head and the high permeability layer in a double—layer—medium is analysed. The soft magnetic underlayer acts as an image plane for the ring—type head. Because of the interaction, the effective component of the recording field increases. The calculation of readback voltage indicates that the readback voltage is stronger than that of single—layer—medium. The effects of ring—type head permeability μ and recording bit length $2L$ on readback voltage are also analysed here.

INTRODUCTION

Perpendicular magnetic recording has been shown to be capable of achieving high recording densities [1]. Initially, R. F. sputtered Co—Cr film was used as anisotropic medium. Subsequently, a composite anisotropic medium consisting of a Fe—Ni soft magnetic film and a Co—Cr perpendicular anisotropic film has been used [2]. Ring—type heads have been used as read heads in perpendicular recording with double—layer media [3]. The presence of the image plane can significantly alter the magnetic field distribution for a ring—type head. The readback voltage is calculated by reciprocity theorem. Results of the calculation are presented and compared with those of a ring—type

head without an image plane. The results of theoretical calculation are helping to supply the optimization design of perpendicular magnetic recording system with theoretical bases.

CALCULATION OF THE RING — TYPE HEAD FIELD

The field produced by actual recording heads is very difficult to calculate without a number of simplifying assumptions. As a result, the following assumptions are used.

- a. The charge density of the pole pieces in the head gap is $\pm I_r$. The other positions of the ring—type head have no charge.
- b. The head is assumed to have infinite pole

tip lengths.

c. The permeability of the head core is assumed to be μ .

d. The soft magnetic underlayer is assumed to have infinite permeability.

e. Both the medium and the air have permeability μ_0 .

f. Geometry and coordinate system used for theoretical analysis is shown in Fig. 1.

Figure. 1. Geometry and coordinate system used for theoretical analysis.

The real head field is [4]:

$$H_{yR} = \frac{I_r}{4\pi\mu_0} \ln \frac{(x_0 + g/2)^2 + y_0^2}{(x_0 - g/2)^2 + y_0^2} \quad (1)$$

According to the imaging principle, the fringe field of the imaging head is:

$$H_{yI} = \frac{-1}{4\pi\mu_0} \int_{2(d+\delta)=y}^{\infty} dy \int_{-\infty}^{\infty} \left\{ \frac{+I_r \left(\frac{\mu - \mu_0}{\mu + \mu_0} \right) (-y_0 + y)}{[(x_0 + g/2)^2 + (y_0 - y)^2 + (z_0 - z)^2]^{3/2}} - \frac{-I_r \left(\frac{\mu - \mu_0}{\mu + \mu_0} \right) (-y_0 + y)}{[(x_0 - g/2)^2 + (y_0 - y)^2 + (z_0 - z)^2]^{3/2}} \right\} dz \quad (2)$$

Integration gives:

$$H_{yI} = \frac{-I_r(\mu - \mu_0)}{4\pi\mu_0(\mu + \mu_0)} \ln$$

$$\frac{[2(d+\delta) - y_0]^2 + (x_0 - g/2)^2}{[2(d+\delta) - y_0]^2 + (x_0 + g/2)^2} \quad (3)$$

H_{yI} in (3) is the increase part of fringe field resulted from the presence of soft magnetic underlayer.

The effective fringe field of the ring-type head in the presence of a soft magnetic underlayer is:

$$H_y = H_{yI} + H_{yR} \quad (4)$$

CALCULATION OF READBACK VOLTAGE FOR AN ISOLATED STEP PERPENDICULAR MAGNETIZATION

It is assumed that the magnetization follows the function:

$$\begin{aligned} M_x(x, y, z) &= 0 \\ M_y(x, y, z) &= M_r \text{Sign}(x_0 - \bar{X}) \\ M_z(x, y, z) &= 0 \end{aligned} \quad (5)$$

Where

$$\text{Sign}(x_0 - \bar{X}) = \begin{cases} 1 & x_0 > \bar{X} \\ -1 & x_0 < \bar{X} \end{cases}$$

The magnetic track width is assumed to be W . Hence, the total flux which enters the coils of the ring-type head is:

$$\varphi(\bar{X}) = \mu_0 W \int_{-\infty}^{\infty} dx_0 \int_{d=y_0}^{d+\delta} M_r \text{Sign}(x_0 - \bar{X}) \cdot H_y dy_0 \quad (6)$$

The readback voltage is:

$$e(\bar{X}) = -aNV \cdot \frac{\partial \varphi(\bar{X})}{\partial \bar{X}} \quad (7)$$

Substituting (4) for H_y in (6) and substituting (6) for $\varphi(\bar{X})$ in (7) give:

$$e(\bar{X}) = e_R(\bar{X}) + e_I(\bar{X}) \quad (8)$$

Where

$$e_R(\bar{X}) = \frac{-\alpha NVWM_r I_r}{2\pi} \left\{ (d + \delta) \ln \frac{(\bar{X} - g/2)^2 + (d + \delta)^2}{(\bar{x} + g/2)^2 + (d + \delta)^2} + d \cdot \ln \frac{(\bar{X} + g/2)^2 + d^2}{(\bar{X} - g/2)^2 + d^2} + 2 \left(\bar{X} - \frac{g}{2} \right) \cdot \left[\operatorname{arctg} \frac{\bar{X} - g/2}{d} - \operatorname{arctg} \frac{\bar{X} - g/2}{d + \delta} \right] - 2 \left(\bar{x} + \frac{g}{2} \right) \cdot \left[\operatorname{arctg} \frac{\bar{X} + g/2}{d} - \operatorname{arctg} \frac{\bar{x} + g/2}{d + \delta} \right] \right\} \quad (9)$$

$$e_I(\bar{X}) = \frac{\alpha NVWM_r I_r (\mu - \mu_0)}{2\pi(\mu + \mu_0)} \left\{ (d + \delta) \cdot \ln \frac{(\bar{X} - g/2)^2 + (d + \delta)^2}{(\bar{X} + g/2)^2 + (d + \delta)^2} - (d + 2\delta) \cdot \ln \frac{(\bar{X} - g/2)^2 + (d + 2\delta)^2}{(\bar{X} + g/2)^2 + (d + 2\delta)^2} - 2 \left(\bar{X} + \frac{g}{2} \right) \cdot \left[\operatorname{arctg} \frac{\bar{X} + g/2}{d + 2\delta} - \operatorname{arctg} \frac{\bar{X} + g/2}{d + \delta} \right] + 2 \left(\bar{X} - \frac{g}{2} \right) \cdot \left[\operatorname{arctg} \frac{\bar{X} - g/2}{d + 2\delta} - \operatorname{arctg} \frac{\bar{X} - g/2}{d + \delta} \right] \right\} \quad (10)$$

$e_R(\bar{X})$ in (9) is the readback voltage of single-layer-medium for an isolated step perpendicular magnetization with a ring-type head. $e_I(\bar{X})$ in (10) is the increase part resulted from the presence of soft magnetic underlayer.

The readback waveforms for $\mu=2000$ or $\mu=4000$ are shown in Fig. 2 respectively.

Figure 2. Readback waveforms for $\mu=2000$ and $\mu=4000$.

According to Fig. 2, the readback voltage is an increasing function of permeability μ .

If the permeability of the ring-type head core is infinite, (8) becomes:

$$e(\bar{X}) = \frac{\alpha NVWM_r I_r g}{2\pi} \left\{ \frac{(d + 2\delta)}{g} \cdot \ln \frac{(\bar{X}/g + 1/2)^2 + (d + 2\delta)/g^2}{(\bar{X}/g - 1/2)^2 + (d + 2\delta)/g^2} - \frac{d}{g} \ln \frac{(\bar{X}/g + 1/2)^2 + (d/g)^2}{(\bar{X}/g - 1/2)^2 + (d/g)^2} - 2 \left(\bar{X}/g + 1/2 \right) \cdot \left[\operatorname{arctg} \frac{\bar{X}/g + 1/2}{(d + 2\delta)/g} - \operatorname{arctg} \frac{\bar{X}/g + 1/2}{d/g} \right] + 2 \left(\bar{X}/g - 1/2 \right) \cdot \left[\operatorname{arctg} \frac{\bar{X}/g - 1/2}{(d + 2\delta)/g} - \operatorname{arctg} \frac{\bar{X}/g - 1/2}{d/g} \right] \right\} = K \cdot \theta(\bar{X}, g, d, \delta) \quad (11)$$

Where

$$K = \frac{\alpha NVWM_r I_r g}{2\pi}$$

$e(\bar{X})$ in (11) is the readback voltage of an isolated step perpendicular magnetization for double-layer-medium with a ring-type head.

$e_R(\bar{X})$, $e_I(\bar{X})$, $e_A(\bar{X})$ are all shown in Fig. 3.

Figure 3. Readback waveform of an isolated perpendicular magnetization.

In the above analyses, the recording bit length is assumed to be infinite. If the recording bit length is $2L$, the readback voltage $\theta_{\max}$ as a function of L is shown in Fig. 4.

Figure 4. Readback voltage $\theta_{\max}$ as a function of L .

CALCULATION OF READBACK VOLTAGE FOR AN ISOLATED ARCTANGENT PERPENDICULAR MAGNETIZATION

It is assumed that the magnetization follows the function:

$$\begin{cases} M_x(x, y, z) = 0 \\ M_y(x, y, z) = \frac{2M_r}{\pi} \arctg \frac{x_0 - \bar{X}}{a} \\ M_z(x, y, z) = 0 \end{cases} \quad (12)$$

The total flux which enters the coils of the ring-type head is:

$$\varphi(\bar{X}) = \mu_0 W \int_{d-\delta}^{d+\delta} dy_0 \int_{-\infty}^{\infty} \frac{2M_r}{\pi} \arctg \frac{x_0 - \bar{X}}{a} \cdot H_y dx_0 \quad (13)$$

The readback voltage is $e(\bar{X})$ in (7). Substituting (13) for $\varphi(\bar{X})$ in (7) and substituting (4) for H_y in (13) give:

$$e_a(\bar{X}) = e_{Ra}(\bar{X}) + e_{La}(\bar{X}) \quad (14)$$

If the permeability of the ring-type head is infinite, $e(\bar{X})$ in (14) becomes:

$$e_a(\bar{X}) = \frac{\alpha N V W M_r I_r}{2\pi} \{ (d + a + 2\delta) \cdot \ln$$

$$\begin{aligned} & \frac{(\bar{X} + g/2)^2 + (d + a + 2\delta)^2}{(\bar{X} - g/2)^2 + (d + a + 2\delta)^2} - (d + a) \cdot \ln \\ & \frac{(\bar{X} + g/2)^2 + (d + a)^2}{(\bar{X} - g/2)^2 + (d + a)^2} - 2(\bar{X} + g/2) \cdot [\arctg \\ & \frac{\bar{X} + g/2}{d + a + 2\delta} - \arctg \frac{\bar{X} + g/2}{(d + a)}] + 2(\bar{X} - \frac{g}{2}) \cdot [\arctg \\ & \frac{\bar{X} - g/2}{d + a + 2\delta} - \arctg \frac{\bar{X} - g/2}{d + a}] \} \end{aligned} \quad (15)$$

$e_a(\bar{X})$ in (15) is the readback voltage of an isolated arctangent perpendicular magnetization for double-layer-medium with a ring-type head. $e_a(\bar{X})$ is shown in Fig. 3 (dashed Curve). If the arctangent transition parameter a is very small, $e_a(\bar{X})$ in (15) will become $e(\bar{X})$ in (11).

CONCLUSION

The magnetic field component of a ring-type head for double-layer-medium in the presence of soft magnetic underlayer is calculated. The magnetic field is stronger than that for the single-layer-medium. The increase part of the magnetic field is H_{y1} in (3). For an isolated step transition in vertical magnetization, the calculated fields are used to compute the voltage induced on the read coil. On the basis of superposition principle, the readback voltage is stronger than that for the single-layer-medium. The increase part is $e_1(\bar{X})$ in (10). According to the readback voltage formula, the readback voltage is an increasing function of permeability μ . If the recording bit length is $2L$, the readback voltage $\theta_{\max}$ versus $\beta = L/g$ is shown in Fig. 4. When β is assumed to be 0.94, the readback voltage $\theta_{\max}$ achieve the maximum. When $\beta \geq 12.41$, the readback voltage $\theta_{\max}$ tends to be steady and approach that of the condition in which

the recording bit length is infinite. The readback voltage of an isolated arctangent perpendicular magnetization is also calculated. The result is $e_a(\bar{X})$ in (14). The width for $e(\bar{X})$ is 90% of that for $e_a(\bar{X})$.

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