ANALYSIS OF THE MUTUAL SELF-BIASED SHIELDED MAGNETO-RESISTIVE HEAD WITH TRANSMISSION-LINE MODEL (I)

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A shielded magnetoresistive (SMR) head which has double MR films and linearizes each other has been designed and studied by applying the transmission-line model. We have analyzed the yoke efficiency, bias efficiency and read efficiency of the SMR head. The read efficiency strongly depends on the height of the sensor and slightly on the other geometric parameters. The yoke and bias efficiencies vary with gap length, insulated layer thickness and relative permeability. A quasi-index reduction in the signal flux is observed when the displacement moves away from the medium.

I. INTRODUCTION

In order to linearize an MR configuration head by rotation of the ferromagnetic layer magnetization toward the hard axis, the magnetostatic bias coupling between the MR layer and the other thin ferromagnetic layer may be used. When the bias layer is made of soft magnetic material, the sensing current in the MR film magnetizes the soft layer, which in turn generates a magnetostatic bias field for MR film. The mechanism of the soft film bias MR head has been described by F. Jeffers et. al. [1]. It is understood that the optimum coupling condition depends on the geometric configuration and magnetic properties of permalloy layer, designing the geometric size and modifying the alloy thin film composition and than the coupling condition is very important for the MR read head engineering [2, 3, 4, 5]. O'Connor et. al. [6] have analyzed the conduct-MR shunt bias head with transmission-line model. The dependence of the saturation behavior on the design parameters and effects of saturation behavior on the performance parameters have also been analyzed. However, the efficiency values of these MR heads are low, less than 35 % and the linearization is not perfect because their model used only conduct current's field (H_b) to linearize unshielded MR head and also had high thermal noise. In this work, a shielded MR head which has double MR films and linearizes each other have been designed. One MR film is a bias layer respect to the other MR film, the magnetostatic field and bias field coupling are used to linearize MR head.

II. TRANSMISSION-LINE MODEL FOR MUTUAL SELF-BIASED SHIELDED MR HEAD

Transmission-line models are very useful in computing the thin film head magnetic circuit, owing to the samll thickness of magnetic layers compared with the other sizes. In an inductive thin film devices, the width W of head is assumed to be very large, so that all the values vary only in the perpendicular direction with respect to the recording medium. Let us consider the shielded MR head which double MR layer are placed between shields 1 and 2 shown in Fig 1. The SMR head has height h, sensing current (I_s) and bias current (I_b) flows through these layers in the Z-direction. The φ_o entering the sensor in the y-direction is generated by the recording medium. Leakage fluxes appear between the MR layers and the shields, causing a progressive reduction in the signal flux within sensor regions distant from the medium.

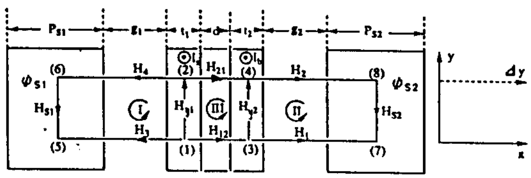


Fig. 1. Computing geometry for transmission-line model

For the MR head, as shown in Fig. 1, the gap fields (H_1, H_2, H_3, H_4) have only x-components, which are function of y displacement alone, while the interlayer fields (H_{y1}, H_{y2}, H_{s1}, H_{s2}) have only the components of y direction. Thus by applying the Gauss's law $\sum \varphi_i = 0$, for nodes (1) through (8), we get the nodes :

$$(1)\quad H_3 + H_{12} = -\frac{1}{\mu_o W}\frac{d\varphi_{y1}}{dy}\Big|_{y-y}$$

$$(2)\quad H_4 + H_{21} = \frac{1}{\mu_o W}\frac{d\varphi_{y1}}{dy}\Big|_{y+\Delta y}$$

$$(3)\quad H_1 - H_{12} = \frac{-1}{\mu_o W}\frac{d\varphi_{y2}}{dy}\Big|_{y=y}$$

$$(4)\quad H_2 - H_{21} = \frac{1}{\mu_o W}\frac{d\varphi_{y2}}{dy}\Big|_{y=y+\Delta y}$$

$$(5)\quad H_3 = \frac{-1}{\mu_o W}\frac{d\varphi_{s1}}{dy}\Big|_{y=y}$$

$$(6)\quad H_4 = \frac{1}{\mu_o W}\frac{d\varphi_{s1}}{dy}\Big|_{y=y+\Delta y}$$

$$(7)\quad H_1 = \frac{-1}{\mu_o W}\frac{d\varphi_{s2}}{dy}\Big|_{y=y}$$

$$(8)\quad H_2 = \frac{1}{\mu_o W}\frac{d\varphi_{s2}}{dy}\Big|_{y=y+\Delta y}$$

If the displacements along x-axis and y-axis directions are signed positive and in turn signed negative, then we get the following equations by applying Ampere's law for loop I, loop II and loop III.

$$(\mathrm{I})\quad H_4[-g_1] + H_{s1}[-\Delta y] - H_3[g_1] + H_{y1}[\Delta y] = \frac{I_s}{(2h)}\Delta y$$

$$(\mathrm{II})\quad -H_2[-g_2] + H_{y2}[-\Delta y] + H_1[g_2] - H_{s2}[\Delta y] = \frac{I_b}{2h}\Delta y$$

$$(\mathrm{III})\quad -H_{21}[-d] + H_{y1}[-\Delta y] + H_{12}[d] - H_{y2}[\Delta y] = \frac{I_s}{(2h)} + \frac{I_b}{2h}\Delta y$$

Considering p_{s1} and $p_{s2} >> t_1$ and t_2, H_{y1} has the same distribution as H_{y2}, $I_s = (t_1/t_2)I_b$, and taking the limits as $\Delta y \to 0$ we obtain two equations for signal flux distribution in double MR element.

$$\frac{d^2}{dy^2}(\varphi_1) - (1/t_1)\left(\frac{1}{g_1} - \frac{1}{d}\right)\frac{\varphi_1}{\mu_r} + \mu_o w\left[\left(\frac{1}{g_1} - \frac{1}{d}\right)(t_1/t_2) - \frac{1}{d}\right]\frac{I_b}{2h} = 0$$

$$\frac{d^2}{dy^2}(\varphi_1) - \frac{2}{\lambda_1^2}(\varphi_1) + \frac{\alpha_1}{\lambda_1^2} I_b = 0 \qquad (1)$$

$$\lambda_1 = (g_1 d \mu_r t_1/(d - 2g_1))^{1/2} \qquad (g_1 < d/2) \qquad (2)$$

$$\alpha_1 = \mu_o w\left[\left(\frac{1}{g_1} - \frac{1}{d}\right)(t_1/t_2) - \frac{1}{d}\right]\frac{\lambda_1^2}{2h} \qquad (3)$$

$$\frac{d^2}{dy^2}(\varphi_2) - (1/t_2)\left(\frac{1}{d} - \frac{2}{g_2}\right)\frac{\varphi_2}{\mu_r} + \mu_o w\left[(t_1/d \cdot t_2 + \frac{1}{d}) - \frac{1}{g_2}\right]\frac{I_b}{2h} = 0$$

$$\frac{d^2}{dy^2}(\varphi_2) - \frac{1}{\lambda_2^2}(\varphi_2) + \frac{\alpha_2}{\lambda_2^2} I_b = 0 \tag{4}$$

$$\lambda_2 = (d.g_2\mu_r t_2/(2g_2 - d))^{1/2}$$

$$(g_2 < d/2) \tag{5}$$

$$\alpha_2 = \lambda_2^2 \left(\frac{\mu_0 w}{2h}\right)\left(\frac{t_1}{d.t_2} + \frac{1}{d} - \frac{1}{g_2}\right) \tag{6}$$

The flux equation is solved in the same manner by considering a general solution type.

$$\varphi_1(y) = A_1 e^{y/\lambda_1} + B_1 e^{-y/\lambda_1} + \alpha_1 I_b \tag{7}$$

$$\varphi_2(y) = A_2 e^{y/\lambda_2} + B_2 e^{-y/\lambda_2} + \alpha_2 I_b \tag{8}$$

Coefficients A and B are determined by using the boundary condition.

$$\varphi_1(0) = \varphi_0,\ \varphi_2(0) = \varphi_0 \tag{9}$$

$$\varphi_1(h) = 0,\ \varphi_2(h) = 0 \tag{10}$$

$$A_i = (\varphi_0 - \alpha_i I_b(1 - e^{h/\lambda_i}))/(1 - e^{2h/\lambda_i}) \tag{11}$$

$$B_i = (\varphi_0 - \alpha_i I_b(1 - e^{-h/\lambda_i}))/(1 - e^{-2h/\lambda_i})$$

$$(i = 1, 2) \tag{12}$$

$$\varphi_1(y) = [\sinh((h - y)/\lambda_i)/\sinh(h/\lambda_i)]\ \varphi_0$$

$$+ [[\sinh((h/\lambda_i) - \sinh((y/\lambda_i)$$

$$- \sinh(h - y)/\lambda_i)]/\sinh((h/\lambda_i)]\ \alpha_i I_b$$

$$\varphi_1 = f_i(y)\varphi_0 + g_i(y)\alpha_i I_b = \varphi_{sig} + \varphi_b$$

$$(i = 1, 2) \tag{13}$$

$$f_i = \frac{\varphi_{sig}}{\varphi_0},\ g_i = \varphi_b/\alpha_i I_b \qquad (i = 1, 2) \tag{14}$$

Here, $f_i(y)$ and $g_i(y)$ are the yoke and bias efficiencies for the SMR head of an unsaturated linear state, respectively. The variation of $f_i(y)/f_i(0)$ and $g_i(y)/g_i(h/2)$ as a function of the displacement y, the relative permeability and the thickness of MR element are shown in Fig. 2.

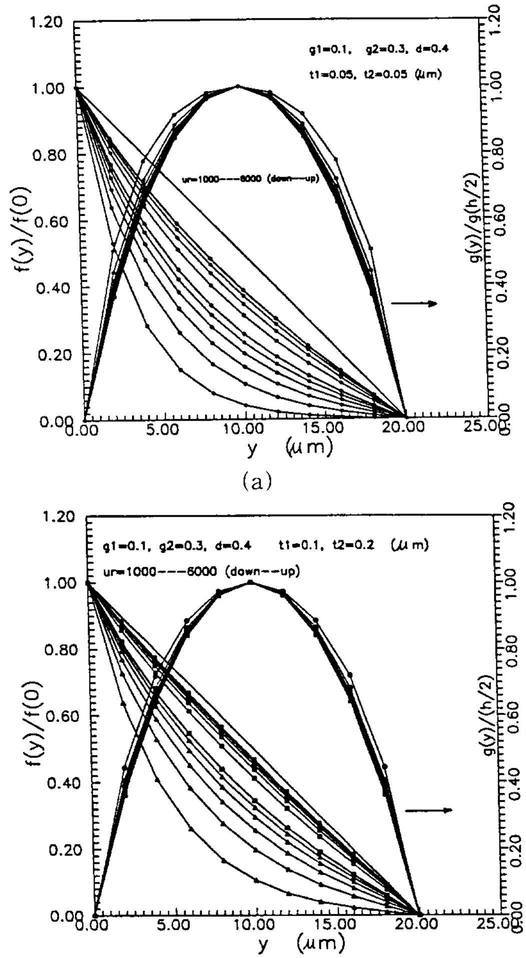
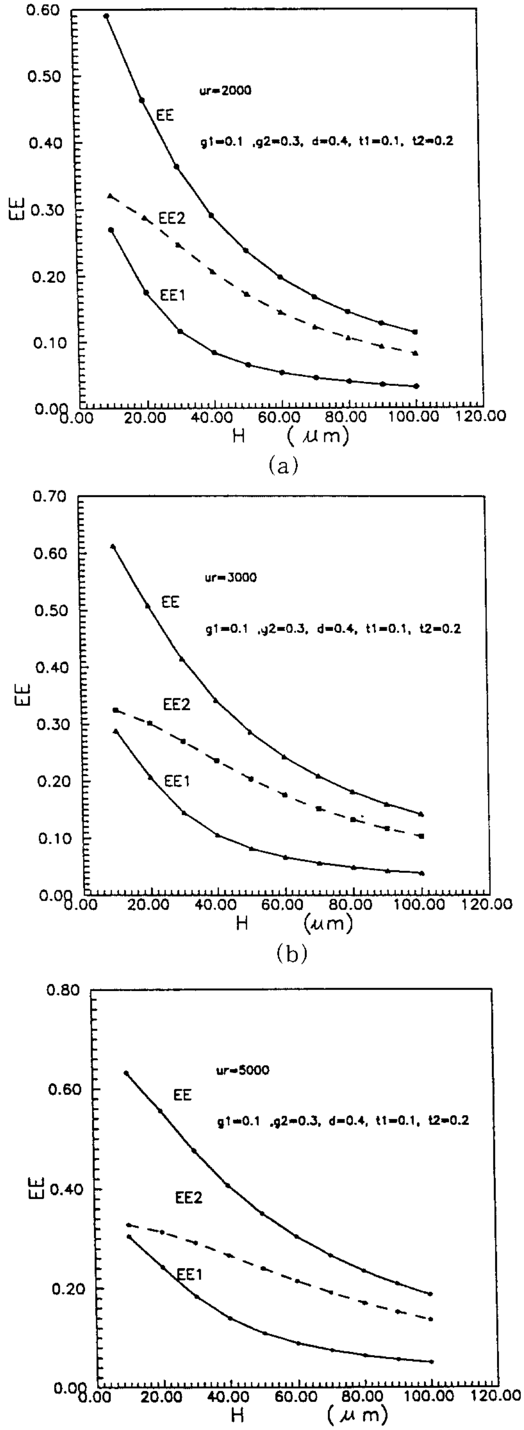


Fig. 2. The yoke and bias effciencies in different permeability and thickness. (a) $t_1 = 0.05\ \mu m$ and $t_2 = 0.05\ \mu m$, (b) $t_1 = 0.1\ \mu m$ and $t_2 = 0.2\ \mu m$

A quasi-index reduction in the signal flux is observed when moving away from the medium, but the bias effect is not uniform. The strong nonuniformity of bias efficiency is due to the boundary conditions used in calculation. The bias field strength is actually double between the edges and the center of the MR layer. As shown in Fig 2. we



(c)

Fig. 3. The total efficiency of SMR head as functions of height and permeability. (a) $\mu_r = 2000$, (b) $\mu_r = 3000$, (c) $\mu_r = 5000$

can see that the two elements are reciprocal each other. The geometric parameters influence only the values of bias and signal field, but don't change the distribution of the field. The magnetic parameters such as permeability slightly increase the signal flux. The total effciency of the device can be defined by averaging the product between the yoke and the bias efficiencies along the height of two MR layers [7], which was shown in Fig. 3.

Here, we observe that the read efficiency of the shielded MR head strongly depends on the height of the sensor and slightly on the other geometric or magnetic parameters. Comparing the common bias MR head with this SMR head, the efficiency value of common single MR element is between 35 and 5 % (EE1, EE2), But for our new SMR read head, the total efficiency value have been improved and the efficiency reaches about 60 %. The efficiency variation as a function of relative permeablity for the SMR head ($g1 + g2 = 0.4$ μm, $d = 0.4$ μm, $h = 20.0$ μm) exhibits an increasing tendency with the increase of permeability.

Ⅲ. CONCLUSION

We have described a double MR elements of the self-biased shielded read head, and discussed the design process and advantage for the head. The yoke efficiency, bias efficiency and total head efficiency have been analyzed by means of transmission-line model. The total efficiency is over 50 % in a relatitve permability range from 2000 to 5000. The MR element with high permeability and lower height would increase the read efficiency. High permeability and optimum thickness can bring a strong signal flux.

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