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

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In order to improve the read-out signal waveform, a shielded magnetoresistive(SMR) head has been designed and studied by applying the transmission-line model. The bias and signal field distribution, the voltage output, the harmonic output signal and resistance value of MR element are simulated as functions of bias current and recording displacement. The results show that the SMR head has good linear character with respect to the medium recording signal in high recording frequency of about 2.5 MHz. The amplitude and waveform of reproduction signal have been obviously improved. The saturation effect on the symmetry and amplitude of reproducing output have also been analyzed.

Ⅰ. INTRODUCTION

Magnetoresistive(MR) head is attractive for high track density recording, because of their high output voltage per unit track width[1]. Potter[2] extended an inductive head model to MR head by adopting an imaginary coil surrounding the MR element. O'connor et. al.[3] discussed the effect of its saturation by introducing a nonlinear effect into the transmission line model. Tsang[4] studied the saturation effect on asymmetry and amplitude of the reproducing output of the MR head. However, these head's efficiency values are low and less than 35 %. This is due to the fact that the magnetic circuit of the read head is an open circuit and the linearization is not perfect, because they only use the field of conduct current(H_b) to linearize MR head and also their model has high thermal noise. In this study, a SMR head which possess double MR films and linearizes each other has been researched. For this SMR head, one MR film is a bias layer with respect to other MR film. The magnetostatic field and bias field coupling are used to linearize SMR head. The bias field, signal field distribution and saturable effect are analyzed. The voltage output and harmonic output signal of the head have been examined as functions of bias current, geometric parameters and recording displacement.

Ⅱ. BIAS FIELD AND SIGNAL FIELD

The transmission-line model can be used not only to evaluate the head operation in unsaturated state, but also to calculate the magnetic field distribution in the MR layer. The magnetic flux is related to the magnetic field as follows :

$$B_y = \frac{\varphi_y}{tW} \tag{1}$$

$$B_b = \frac{\varphi_b}{tW} \tag{2}$$

According to equation (1) and (2), the curves of bias magnetic field (B_{b1}, B_{b2}) and signal field (B_{y1}, B_{y2}) as a function of y displacement are shown in Fig. 1 and Fig. 2, respectively.

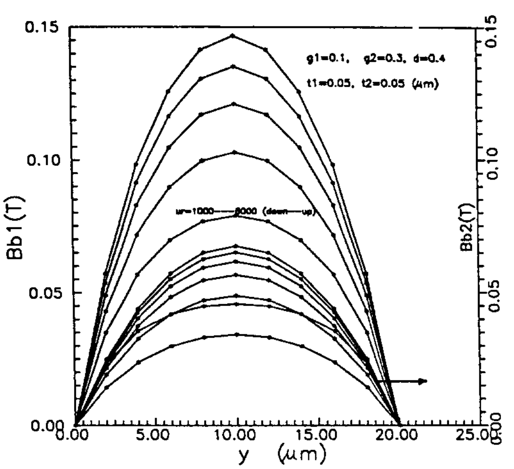

Fig. 1. The bias field (B_{b1}, B_{b2}) distribution in double MR element

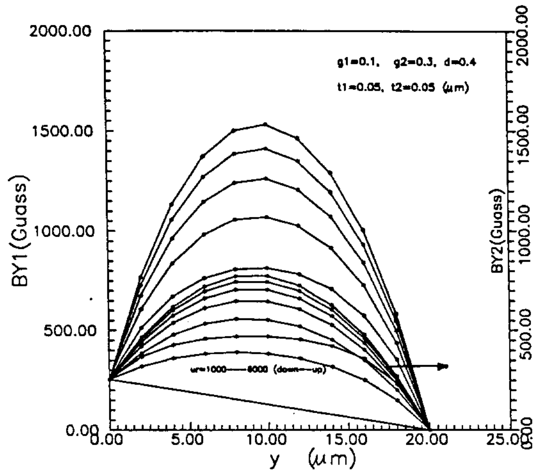

Fig. 2. Signal field (B_{y1}, B_{y2}) distribution in two MR elements

Here, we notice that the bias field strongly depends on relative permeability (μ_r), the bias current (I_b), the gap length (g_1, g_2) and the insulated layer thickness (d). In order to make the MR sensor working on unsaturated state, several parameters should be optimized. Saturation may occur for two reasons : the increase in bias current strength or the close proximity of the MR element to one of the shields. In these curves, the bias field has the value sufficient to rotate magnetization into a suitable angle with respect to the easy axis, the range of bias field is from 0.01 T to 0.3 T. The value of bias field represents maximum value in the middle of MR film (y-axis direction), while zero at the boundary.

The signal field distribution also depend on the relative permeability (μ_r), gap length (g_1) and (g_2) and the insulated layer thickness (d). The variation of signal field with y displacement is obvious and have a maximum value at central range of MR element. Taking $I_b = 20$ mA, $g_1 = 0.1$ μm, $g_2 = 0.3$ μm, d = 0.4 μm, $t_1 = 0.1$ μm and $t_2 = 0.2$ μm, the signal field B_{y1} varies from 1000 to 2500 gauss, B_{y2} varies from 250 to 500 gauss with increasing the relative permeability. Even though the signal field distribution $B_{y1}(y)$ is the same as $B_{y2}(y)$, but the amplitute is different.

Ⅲ. THE VOLTAGE OUTPUT AND HARMONIC OUTPUT SIGNAL OF SMR HEAD

It is assumed that the medium is sinusoidally magnetized and its magnetization is constant through the medium thickness. The readback flux equation in y = 0 is given from Potter's relation [2].

$$\varphi(0) = \mu_0 M_r \delta\, W e^{-kr}(1-e^{-k\delta})/k\delta$$

$$*[[f(g_1)]^2 + [f(g_2)]^2 - 2f(g_1)f(g_2)$$

$$\cos[k(g_1+g_2+2t_1+2t_2)/2]]^{1/2}$$

$$*\cos(KX+\psi) \qquad (3)$$

$$k = 2\pi/\lambda$$

$$f(g_i) = \sin(\pi g_i/\lambda)/(\pi g_i/\lambda) \qquad (i = 1, 2) \text{ and}$$

$$\psi = tgn^{-1}[f(g_1A_1 + f(g_2A_2]/[f(g_1B_1 + f(g_2B_2]$$

$$A_1 = \sin[k(g_1+t_1+t_2)/2]$$

$$A_2 = \sin[k(g_2+t_1+t_2)/2]$$

$$B_1 = \cos[k(g_1+t_1+t_2)/2]$$

$$B_2 = \cos[k(g_2+t_1+t_2)/2]$$

$$X = V*\tau$$

where λ is the recording wavelength, r the head-to-medium spacing, δ the medium thickness, M_r the medium remanence, X the location with respect to the head of coordinate system in the medium at time τ and V the medium moving velocity.

Once the solutions for φ_{yi} and B_{yi} are obtained and the resistivity at each point with respect to the y direction for the MR element is given by Shelledy and Brok's equation[5].

$$\rho_i(y, \tau) = \rho_0 + \Delta\rho_{max}[1 - [B_{yi}(y, \tau)/B_s]^2] \quad (4)$$

Now, let us consider two kinds of circuit connection shown in Fig. 3.

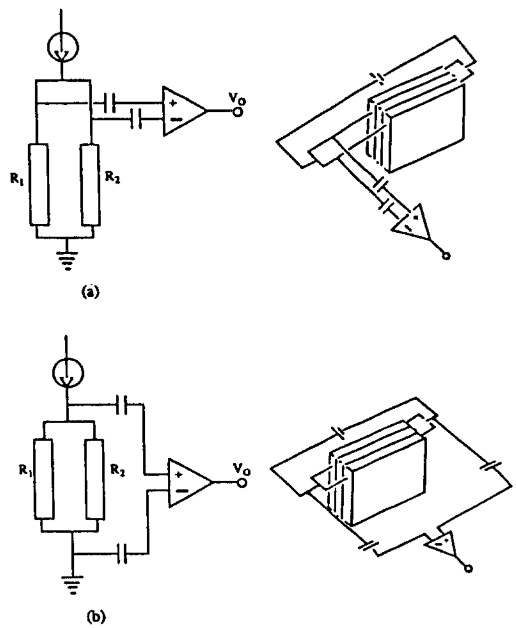

Fig. 3. The circuit connection of mutual self-biased shielded MR head (a) type connection, (b) type connection

For the (a) SMR head, the voltage output and the harmonic output signal (HOS) are given as follows :

$$V(\tau) = \sum_{i=1}^{2} I_i R_i \quad (5)$$

$$R_i(\tau) = [\int_0^h \frac{t_i}{W\rho_i} dy]^{-1} \quad (6)$$

$$HOS = 20 * Log| \frac{V(\tau)}{V_0} | \quad (7)$$

$$V_0 = I_b\rho_0 \frac{W(\tau)}{h} [1/t_1 + t_2] \quad (8)$$

For (b) type SMR head, the voltage output and harmonic output signal (HOS) are given below :

$$V(\tau) = I_b * (R_1R_2/(R_1 + R_2)) - V_0 \quad (9)$$

$$R_i(\tau) = [\int_0^h \frac{t_i}{W\rho_i} dy]^{-1} \quad (10)$$

$$V_0 = I_b\rho_0 \frac{W(\tau)}{h} [1/t_1 + t_2] \quad (11)$$

$$HOS = 20 * Log| \frac{V(\tau)}{V_0} | \quad (12)$$

The voltage output and the harmonic output signal as functions of bias current are shown in Fig. 4 and Fig. 5, respectively. The resistance value of MR element as a function of bias current is shown in Fig. 6.

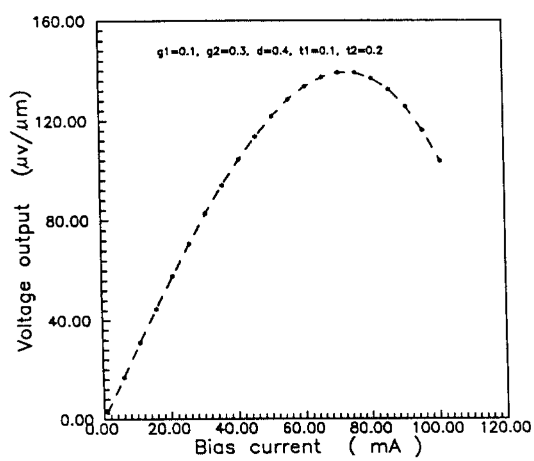

Fig. 4. The voltage output as a function of bias current

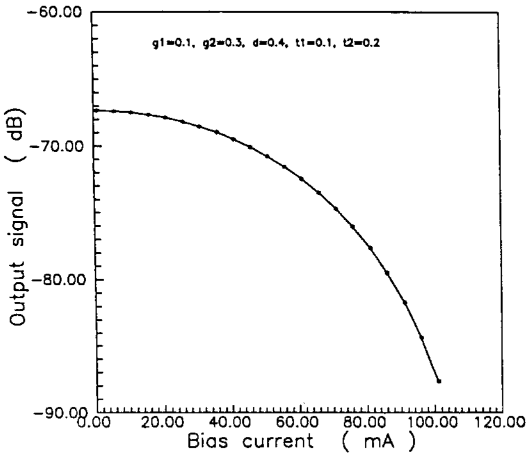

Fig. 5. The harmonic output signal as a function of bias current

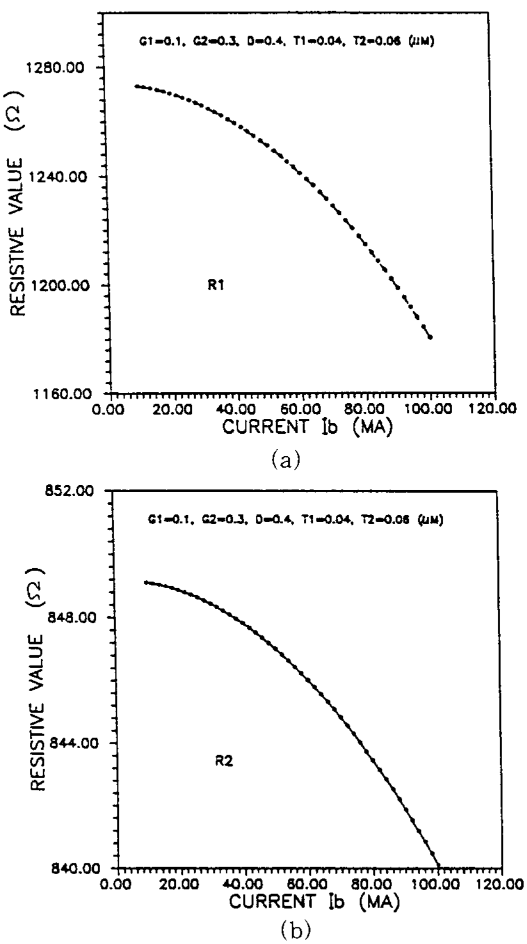

Fig. 6. The resistance value as function of bias current (a) R_1 curve and (b) R_2 curve

The amplitude of voltage output increases with bias current increasing in the range of 0~70 mA. There is a saturation point at the bias current of 70mA. Beyond the 70 mA, the value of voltage output is steeply decreased. Therefore, the optimum value of the bias current is between 40 and 70 mA for the SMR head. The harmonic output signal also has an increasing tendency with increasing bias current, suggesting that the bias current exerts an influence on the resistance value of MR element as shown in Fig. 6.

The variation of the voltage output and the harmonic output signal with recording displacement are shown in Fig. 7 and Fig. 8, respectivively.

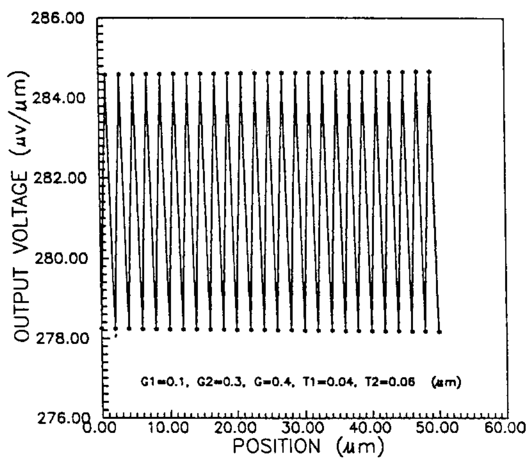

Fig. 7. The voltage output as a function of the recording displacement

As shown in Fig. 7, the voltage output shows sinusoidal distribution which is the same as the recording signal in the medium and, therefore, it is implied that the SMR head's design is successful and better than the common MR head. The circle on the curve is equal to 0.4 $\mu s (\tau = \triangle X / V)$, which determines that the recording frequency is about 2.5 MHz (medium velocity is equal to 5 m/s).

The harmonic output signal in Fig. 8 shows a symmetrical waveform with respect to the zero position between the positive and negative half circle and the average signal amplitude is as high as 71.10 dB. So the SMR head connected as this circuit type has an advantage to the common head.

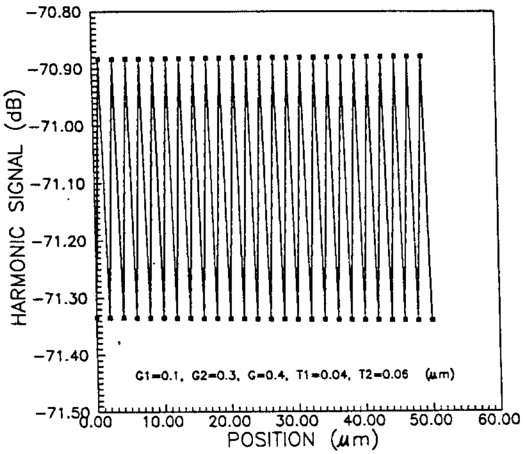

Fig. 8. The HOS as a function of the recording displacement

Ⅳ. CONCLUSION

Based on the transmission-line model, the bias and signal field distribution and the resistance value of MR element as a function of y displacement have been investigated on the view points of the bias current (I_b), the gap length (g_1, g_2), the insulated layer thickness (d) and the relative permeability (μ_r). The variation of voltage output and HOS with bias current and the recording displacement have also been simulated. The bias current is the most important parameter for the voltage output and HOS, even though the voltage output increases with increasing bias current for the head, There is a saturable point at 70 mA and above the 70 mA the MR element is saturated. The optimum value of bias current may be selected between 40 and 70 mA. The HOS have an increasing tendency with increasing bias current. The variation of voltage output and HOS with the recording displacement shows a normal sinusoidal distribution, implying that the SMR head has good linear characteristics with respect to the medium signal in high recording frequency of about 2.5 MHz.

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