THE EFFECT OF MAGNETIC INTERACTION BETWEEN MEDIUM AND HEAD ON PERPENDICULAR MAGNETIC RECORDING CHARACTERISTICS

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Abstruct - The high density recording characteristics of perpendicular magnetic recording using a single-pole head are affected by the magnetic interaction between the medium and the head. By decreasing the relative thickness of the Co-Cr layer in the double-layer medium to that of the main-pole of the head, and increasing the saturation magnetization of the Co-Cr layer, the high density recording characteristics are enhanced. When requisite conditions are realized, the reproduced voltage vs. bit density characteristics are improved considerably for a thinner main-pole of the single-pole head.

INTRODUCTION

A single-pole head for perpendicular magnetic recording excels in generating so purely perpendicular magnetic field that media having perpendicular anisotropy can be recorded with very high bit density of over 200 kFRPI. The practical recording and reproducing characteristics however are determined primarily by the perpformance of the head. A double-layer medium backing a soft magnetic layer under a Co-Cr layer was proposed to develop the capability of the single-pole head [1]. The effect of the soft magnetic underlayer on the recording and reproducing characteristics was investigated theoretically and experimentally in many papers [2, 3, 4, 5]. However it cannot be also disregarded that the magnetized Co-Cr layer interacts magnetically with the main-pole of the single-pole head and affects on the recording and reproducing sensitivities and resolutions.

It is shown here that the magnetic interaction between the main-pole and the Co-Cr layer have an effect on the bit density response, the reproduced voltage and the head-to-medium spacing loss in perpendicular magnetic recording.

HEAD-TO-MEDIUM MAGNETIC INTERACTION

Effective susceptibility

A main-pole magnetized with the intensity of M_h arises the demagnetizing field, $H_d = 2\pi M_h$, on the main-pole top surface, as shown in Fig.1. When a medium is in close to the main-pole and is magnetized with the intensity of M_m, however the field, $H_m = D \cdot M_m$, adds to H_d in the inverse polarity. Hence the main-pole is magnetized as follows,

$$M_h = \chi_{int} \cdot [H_a - 2\pi M_h + D \cdot M_m] \qquad (1),$$

where H_a is external field generated by a current in a coil wound around the main- or the auxiliary-pole, and χ_{int} is the intrinsic susceptibility of the main-pole film. If it can be assumed that H_m arises from charges distributed on the Co-Cr surface over the same area as that of the main-pole top surface facing the medium, the head-to-medium geometry function, D, is given by

$$D = (2/\pi) \cdot \arctan(T/2d) \qquad (2),$$

where T is the main-pole thickness and d is the spacing between the medium and the main-pole. Here, if m is the ratio of M_m to M_h, the effective susceptibility, $\chi_{eff} = M_h/H_a$, on the main-pole top is derived as follows,

$$\chi_{eff} = \chi_{int}/[1 + 2\pi\chi_{int}(1 - m \cdot D)] \qquad (3),$$

From Eq.(3), we can basically understand the magnetic interaction of media to a main-pole as follows;

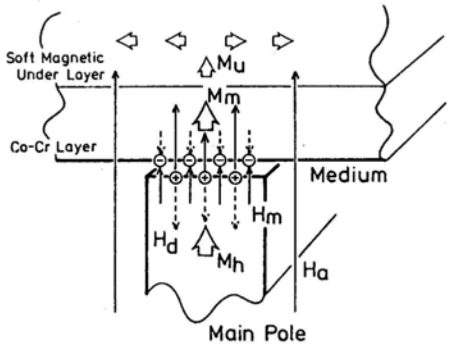

Fig.1 Schematic diagram of magnetic interaction between the main-pole of a single-pole head and the Co-Cr layer of a double-layer medium.

i) When the main-pole is in free space, the sensitivity of the main-pole takes a very low value of $1/2\pi$, because m = 0. Therefore the main-pole suface is hardly magnetized as the magnetic flux flows through the sides of the main-pole.

ii) When the main-pole is in close to the medium and if the Co-Cr layer is magnetized with a similar intensity as that of the main-pole, the sensitivity increases greatly to near χ_{int} because (m · D) approaches 1.

Head field distribution

Fig.2 shows the perpendicular field distributions, obtained by the finite-element method (FEM) [6], on (a) the top surface of the Co-Cr layer and (b) the interface of the Co-Cr and the soft magnetic underlayer. Curves A, B and C correspond respectively to those in the absence of any medium, in the presence of Ni-Fe underlayer alone and the double-layer medium.

In the calculation, the initial magnetization curve of a 80%Ni-20%Fe film for the M-H loops of the underlayer and the main-pole and an isotropic initial magnetization curve with a permeability of 5 for the Co-Cr layer were used, respectively [6]. The thicknesses of the main-pole, the Co-Cr layer and the Ni-Fe layer were 0.8, 0.2 and 0.5 microns, and the spacing between the main-pole and the medium was 0.1 microns.

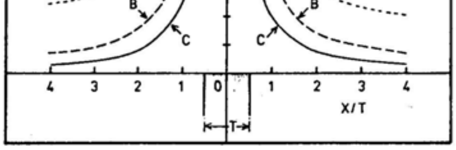

Fig.2 Perpendicular field distributions on (a) the surface of the medium and (b) the interface of the Co-Cr layer and the soft magnetic underlayer. Curves A, B and C correspond to the field distribution in the absence of any medium, in the presence of the Ni-Fe underlayer alone, and the double-layer medium.

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The head field strength and distribution in the presence of the double-layer medium becomes more intense and sharp than those in the presense of the underlayer alone [6, 7], as shown by curve C. Consequently, the head-to-medium magnetic interaction occurs effectively under the following conditions; i) The sum of the head-to-medium spacing, d, and the Co-Cr layer thickness, δ, is smaller than the main-pole thickness, T, ii) The magnetization, M_m of the Co-Cr layer is as large as those of both the main-pole and the soft magnetic underlayer.

RECORDING AND REPRODUCING CHARACTERISTICS

Bit density response

When the width of magnetization transition is much narrower than the main-pole thickness, the reproduced voltage vs. bit density characteristices can been estimated by a superposition of isolated pulses which can be approximated by the head field distribution [9]. For that, three isolated pulse shapes were assumed by the distributios of head field, as shown by curve I, II and III in Fig.3. Curves I and II were obtained by the boundary-element method (BEM) [10] for a ring head without any medium and for a single-pole head with a soft magnetic underlayer alone. The underlayer was positioned apart from the main-pole with the distance of 0.12 microns which is the sum of the head-to-medium spacing of 0.02 microns and the Co-Cr layer thickness of 0.1 microns. Both the gap length and the main-pole thickness were assumed as 0.35 microns. On the other hand, curve III is a Karlqvist type field distribution, which was calculated by assuming magnetic charges uniformly distributed on the main-pole top surface and its images in the underlayer. The shape is similar to that obtained by FEM, as shown by curve C in Fig.2.

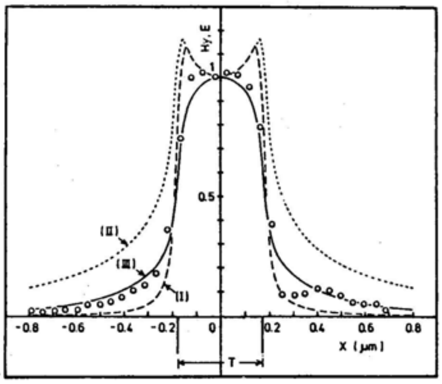

Fig.3 Isolated pulse shapes assumed by the field distributions. Curves I and II are obtained by BEM for a ring head without any medium and a single-pole head with a soft magnetic underlayer alone. Curve III is obtained by assuming uniformly distributed charges on the main-pole top surface and its images in the underlayer. Open circles show a measured pulse shape.

The bit density responses obtained by the superposition of each distribution are shown by solid, broken and dotted lines in Fig.4, and they are compared with the measured values, plotted by open circles. A heavy line was obtaines by the superposition of the measured iolated pulse. The measurement has been carried out by using a double-layer medium consisting of an 0.1 microns thick Co-Cr layer and an 0.5 microns thick Cu-Mo-Ni-Fe underlayer, and an 0.35 microns thick main-pole. The perpendicular coercivity and the saturation magnetization are 500 Oe and 830 emu/cc. The actual head-to-medium spacing, d, in our tape-driving-system used was 0.02 microns which was measured by an optical interferometric technique at tape speed of 4.75 cm/sec.

The isolated pulse had a trapezoidal shape whose half pulse width is about 0.4 microns even for 0.35 microns thick main-pole. The ratio of the second peak after the first null to the isolated pulse peak was over 80% at about 200 kFRPI, and the D_{50} on the envelope of the response curve (D_{50}^*) reached about 260 kFRPI. The reproduced pulse has a intermediate shape of the distributions of the ring head field and the Karlqvist type field, and the bit density response is also intermediate between those curves obtained by using both the distributions. Consequently, when the geometry and the magnetic property of the Co-Cr layer is optimized to those of the main-pole so as to arise effectively the head-to-medium magnetic interaction, the actual field distibution becomes much sharper than that obtained by the calculation assuming equi-potentials on the underlayer and the main-pole surface.

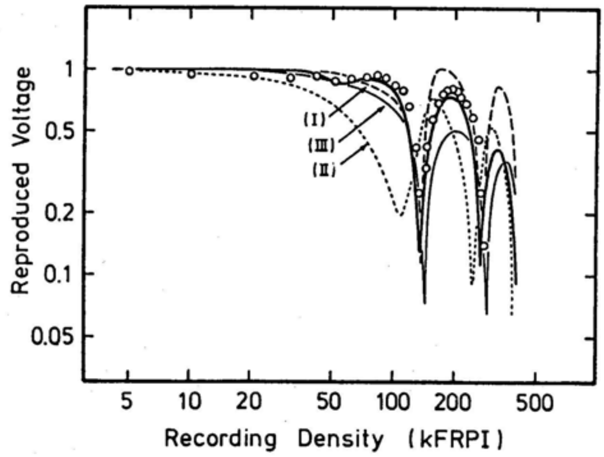

Fig.4 Bit density responses obtained by the superposition of each isolated pulse, corresponding to curves I, II and III in Fig.4. Open circles are measured one and a heavy line is obtained by a superposition of the measured pulse.

Correlation with medium parameters

The amplitude, E_p of reproduced voltage at low density depends not only on the height of head field distribution but also on the intensity of remanent magnetization and the thickness of a Co-Cr layer, because the transition width is much narrower than a main-pole thickness but is not zero. Therefore E_p depends on the saturation magnetization, M_s, the thickness, δ, and the perpendicular coercivity, $H_{c\perp}$, [11], and their correlation will be expressed approximately as follows,

$$E_{p,L} = C_1 \cdot (\delta \cdot M_s \cdot H_{c\perp})^P \qquad (4).$$

On the other hand, E_p mainly depends on the sharpness of the head field distribution at high density, because the isolated pulses interfere with each other, as mentioned above. Therefore E_p is affected by the degree of the head-to-medium interaction, and the correlation is expressed as follows, independently af $H_{c\perp}$,

$$E_{p,H} = C_2 \cdot (M_s/\delta)^Q \qquad (5).$$

Hence D_{50}^* on the envelope of the bit density response, eliminating the influence of the main-pole thickness null, will obey the following correlation,

$$D_{50}^* = C_3 \cdot [M_s/(\delta \cdot H_{c\perp})]^R \qquad (6).$$

To confirm these correlations, the measurement has been carried out for many media having the Co-Cr layer of the thickness of 0.1 to 0.5 microns, the perpendicular coercivity of 370 to 750 Oe, and the saturation magnetization of 230 to 830 emu/cc. Single pole heads used have the mian-pole thickness of about 0.3 and 0.9 microns. In the measurement, it is confirmed that the exponents P, Q and R were nearly equal to 1.

Fig.5 shows a correlation of the amplitude, $E_{p,H}^*$, of reproduced voltage to various (M_s/δ) at 150 kFRPI on the envelope of the bit density response. When the Co-Cr layer is much thinner than the main-pole thickness, D_{50}^* obeys the above correlation of Eq.(5) [12], but $E_{p,H}^*$ does not obey, because the remanent magnetic moment of the Co-Cr layer becomes too small to get a higher reproduced voltage even at high bit density.

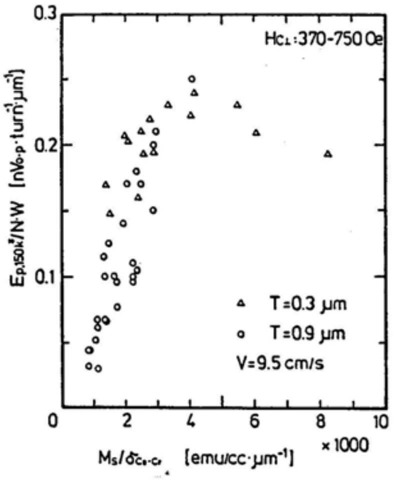

Fig.5 Correlation between the amplitudes of reproduced voltage at high density and media parameters.

EFFECT OF HEAD-TO-MEDIUM SPACING

The head-to-medium magnetic interaction has also an effect on the spacing loss for the double-layer medium having a high permeable layer. If an increasing rate, η, of the head sensitivity can be expressed by the ratio of the effective susceptibilities, χ_{eff}, in the presense and absense of the medium, the spacing effect on the reproduced voltage at recording wavelength, λ, should be expressed as follows,

$$E_d(d) \propto \eta \cdot \exp(-2\pi d/\lambda) \qquad (7).$$

In Eq.(3), usually the intrinsic susceptibility, χ_{int}, of a main-pole is much larger than 1. Therefore the increasing rate, η, of the head sensitivity can be given approximately as follows,

$$\eta = 1/(1 - m \cdot D) \qquad (8).$$

The increasing rate, η, vs. relative spacing, (d/T), estimated by using Eq.(8) for the various values of m shown in Fig.6. On the other hand, Fig.7 shows the spacing effect measured for the media having the Co-Cr layer of various saturation magnetizations. As expected from Fig.6, the amplitude of reproduced voltage deviates from a spacing loss line of -54.6 d/λ (dB) with decreasing the spacing and increases more at smaller spacing, when the Co-Cr layer has the higher saturation magnetization. Similar spacing effect for thinner Co-Cr layers and thicker main-poles [12] can be also estimated by assuming that the main-pole magnetically interacts in following two steps; firstly with the soft magnetic underlayer and secondly with the Co-Cr layer.

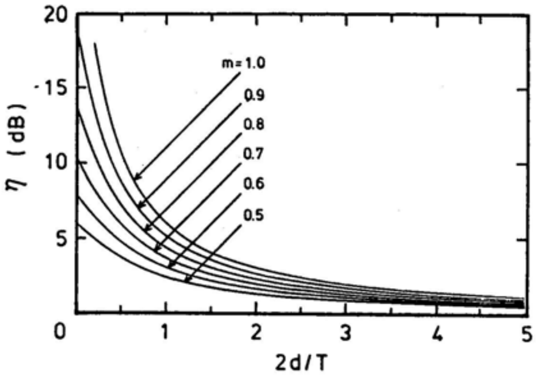

Fig.6 Increasing rate, η, of head sensitivity vs. relative head-to-medium spacing to main-pole thickness, calculated for various ratios, m, of the magnetization of Co-Cr layer to that of main-pole.

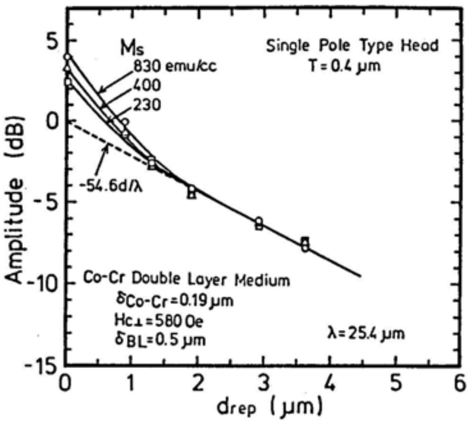

Fig.7 Amplitude of reproduced voltage vs. head-to-medium spacing measured for media having Co-Cr layers of various saturation magnetizations.

CONCLUSION

The magnetic interaction between the single-pole head and the double-layer medium has an important effect on the sensitivity and resolution of the head in perpendicular magnetic recording and reproducing. The desirable effect can be achieved not only by the soft magnetic underlayer but also by the Co-Cr layer of the medium. The relatively thinner Co-Cr layer to a main-pole thickness, the higher saturation magnetization of the Co-Cr layer having perpendicular anisotropy and the smaller head-to-medium spacing result in the higher reproduced voltage at a higher bit density.

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