THE MAGNETIC FIELD DISTRIBUTION OF A PERPENDICULAR RECORDING HEAD

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ABSTRACT

The magnetic field distribution of the perpendicular recording head has been investigate using a large scale model. This paper discusses the field distribution of the actual head from the measured results in the model head. It is shown that the strength of head field increases and the field distribution becomes very sharp because of the interaction between the head and the medium. The perpendicular recording which consists of the head having the sharp field distribution and a perpendicular anisotropy medium results in the demagnetization-free recording in very high densities.

I. INTRODUCTION

A perpendicular magnetic recording system[1,2] is essentially suitable for a high density recording which uses a recording medium having perpendicular anisotropy and a recording head of modified single pole type.[2] This type of head produces the sharp and pure perpendicular magnetic field as compared with a ring type head.

In our experiments of the perpendicular recording, the single pole head energized by an auxiliary pole was used. This head has the same field distribution over a wide range of the magneto-motive force (MMF) as compared with other types of the single pole head. This head also has practical merits that the auxiliary pole can be placed apart from the recording medium and that the wear of the main pole does not influence the shape of the perpendicular field distribution since the auxiliary pole is far thicker than the main pole.

It is hardly possible, however, to theoretically obtain the field distribution using a Schwarz-Christoffel transformation because the magnetic potential of the newly proposed perpendicular head cannot be exactly given as in the analysis of the ring type head.[3,4] The field distribution of the ordinary probe type perpendicular head was visualized in terms of the electrical-resistor analogue.[5] In this paper, the magnetic field distributions around the main pole, which were directly measured using a large scale model of the perpendicular head, are shown. Moreover, the characteristics of the magnetic field of the actual head will be discuss on the basis of the measured field distributions of the model head.

II. EXPERIMENTS WITH LARGE SCALE MODEL

The fundamental structure of the perpendicular type head (type I) is shown in Fig.1(a).[2] The main pole of the magnetic film is either in contact with or close to the recording medium to record signals. The auxiliary pole is very large in size compared with the main pole and is positioned on the other side of the recording medium. The recording field is produced by the main pole which is magnetized from its pole tip by the auxiliary pole field. In this structure, the perpendicular field can always be applied to the medium, with no factor to tilted the field from the normal of the medium. In this section, the type I head is compared with two different types of head in which the main pole is directly energized by a winding around it with (type II) and without (type III) the auxiliary pole as shown in Fig.1(b) and (c), respectively.

In order to investigate the magnetic field distribution around the main pole, a model head was constructed, in which the main pole thickness T_m was scaled up $10^3 \sim 10^4$ times as thick as the actual head. The material of the model head was pure Fe. The thickness T_m and T_a of the main and the auxiliary poles are 10 mm and 70 mm, respectively, and the distance S between the main and auxiliary poles is 100 mm. The length and the width of both poles are 600 mm and 150 mm, respectively. In actual heads, T_m, T_a and S are $1 \sim 5$ μm, $0.1 \sim 1$ mm and 0.1 mm, respectively. The field strength depends upon S in type I head, but the shape of field distribution is independent of S and T_a if they are much greater than T_m.

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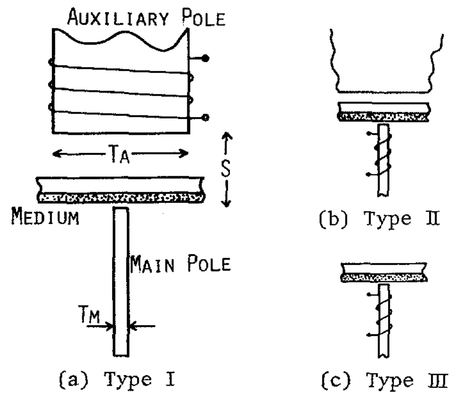

Fig.1. Structure of perpendicular recording head.

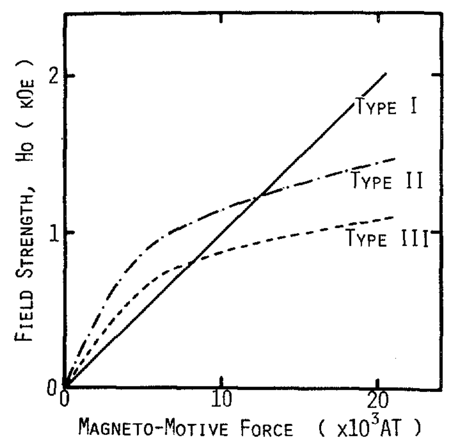

Fig.2. Magnetic field strength vs. magneto-motive force of model head. (S/T_m = 10 for type I and 5 for type II)

Fig.2 shows the perpendicular field strength at the center of the top surface of the main pole versus MMF of the model head for the three types. The magnetic field of the head of type I (solid line) linearly increases over a wide range of MMF, since the main pole is magnetized from its tip by the auxiliary pole field. The main pole placed close to the auxiliary pole produces stronger field. In type II (dot-dash-line), the magnetic field is slightly increased as compared with type III (broken line) because of the image effect of the auxiliary pole but the magnetization saturation occurs at the thin film yoke beneath the coil as in the case of type III. Thus, the head of type I shows the best performance on the linearity.

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The magnetic field distribution around the main pole of type I is shown in Fig.3. The origin of the co-ordinate is at the center of the top surface of the main pole. The solid and broken lines represent respectively the perpendicular component H_y and the longitudianl component H_x which are all normalized by the perpendicular field strength at the origin. Since the thickness of the main pole is very small compared with both the thickness of the auxiliary pole and the distance between the two poles, the magnetic field H around the main pole can be expressed as a vector sum of the main pole field H_m and the auxiliary pole field H_a. The H_m and H_a act in the opposite polarity on H_x, while in the same polarity on H_y. Therefore, H_x becomes small but the base of H_y is lifted due to the contribution of H_a.

From the results of the large scale model, the perpendicular field distribution of the actual head will be estimated in the following section.

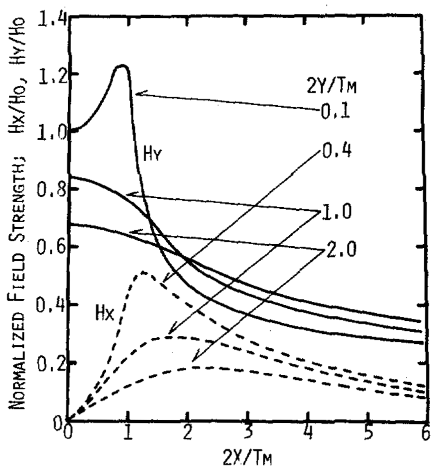

Fig.3. Magnetic field distribution around main pole of model head. (S/T_m = 10, T_a/T_m = 7)

III. FIELD DISTRIBUTION OF ACTUAL HEAD

In the head of type I, the magnetic field distribution function F normalized by the perpendicular field strength at the origin, which is the center of the top surface of the main pole, can be expressed by[6]

$$F = (1 - A)\cdot F_m + A\cdot F_a, \tag{1}$$

where F_m and F_a are the field distribution functions of the main and the auxiliary poles which are both normalized by respective perpendicular field strength, and A is the ratio of the auxiliary pole field to the total field. Using the sensitivity μ_{me} of the main pole to the auxiliary pole field, A is given by

$$A = 1 / (1 + \mu_{me}). \tag{2}$$

We define μ_{me} as the ratio of the main pole field to the auxiliary pole field at the origin. It is physically equivalent to the local permeability at this particular point because of the continuity of flux density on the top surface of the main pole. μ_{me} of the main pole of the actual head in eq.(2) can be estimated as follows.

When the auxiliary pole field H_a is applied to the main pole, the perpendicular component of the magnetization at the origin is given by

$$M_y = \kappa_m\cdot(H_{ao} - N\cdot M_y), \tag{3}$$

where κ_m is a susceptibility of the main pole film and N is a demagnetizing factor at the origin. N in eq.(3) depends mostly upon the thickness T_m of the main pole, since T_m is usually much less than the length and the width of the main pole. N is decided from the magnetic charge distributions on the top and side surfaces of the main pole. Then, N approaches, for very thick T_m, to 2π which corresponds to the demagnetizing factor on the infinite plane, while N approaches to zero for very thin T_m.

On the other hand, the main pole field produced by M_y at the origin is given by

$$H_{mo} = (4\pi - N)\cdot M_y. \tag{4}$$

From eq.(3) and (4), μ_{me} of the main pole can be derived as eq.(5), because κ_m is very large,

$$\mu_{me} = \frac{4\pi - N}{(1/\kappa_m) + N} \cong \left(\frac{4\pi}{N}\right) - 1. \tag{5}$$

Consequently, μ_{me} usually depends upon the demagnetizing factor N or T_m alone. To confirm this relation, μ_{me} was measured for the different thicknesses and materials of the main pole of the model head. It was obtained that μ_{me} increases in proportion to $T_m^{-0.5}$ for T_m < 100 mm independently of the materials, while μ_{me} approches to 1.0 for T_m > 100 mm. By applying these relations to the actual head, μ_{me} becomes about 150 for T_m = 5 µm. This value almost agrees with the permeability of the main pole which is experimentally measured by a one-turn coil winding around the tip.

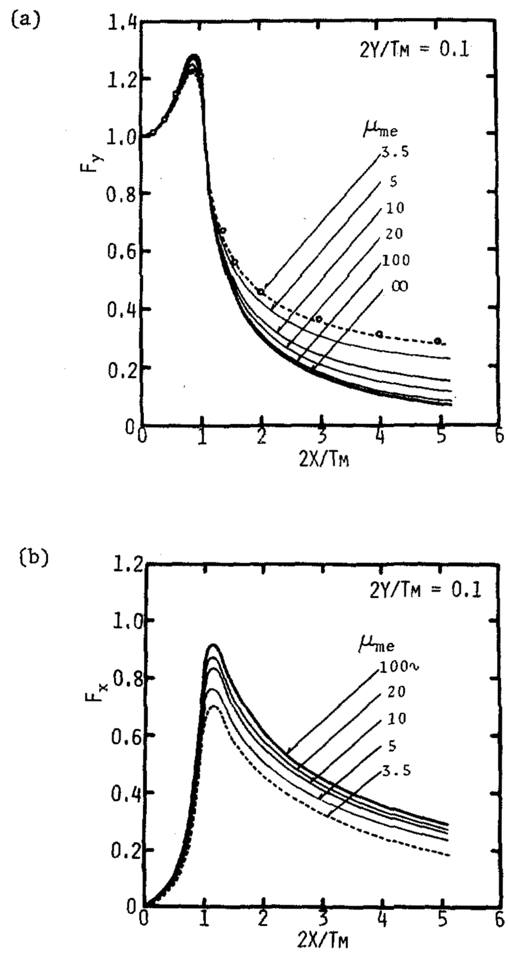

Fig.4. Calculated magnetic field distributions of perpendicular component (a) and longitudinal component (b) for various μ_{me}.
∘ : Measured in model head
--- : Calculated for model head

Fig.4(a) and (b) show the calculated field distributions of the respective perpendicular F_y and longitudinal F_x components of F in the layer of $y/T_m = 0.05$ for different μ_{me} values. Fig.4(a) also shows the measured values of the model head (open circle), which correspond to the theoretical case of $\mu_{me} = 3.5$ (broken line). As can be seen from the figure, F coincides almost with F_m when μ_{me} is greater than 100. The longitudinal component slightly increases with the increase of μ_{me} while the perpendicular component remarkably changes to the sharper distribution which rapidly decreases with the increase of the distance from the main pole edge.

IV. DISCUSSION

In the perpendicular recording head, however, the interaction between the head and the medium cannot be ignored. When the recording medium is close to the main pole, N decreases, since the magnetic field produced by the magnetized medium is superposed on the demagnetizing field in the main pole in the opposite polarity. Then, it is expected that the decrease in N results in the increase in the main pole field.

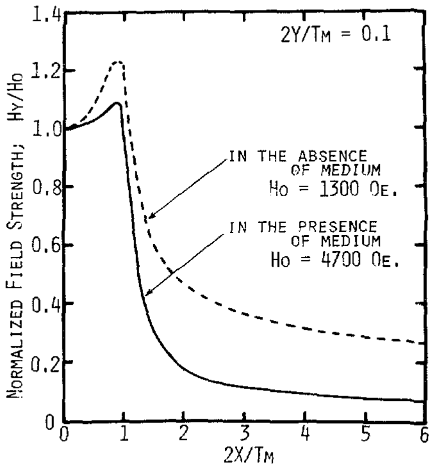

Fig.5. Comparison of magnetic field distributions in absence and presence of medium.

Fig.5 shows the measured distributions of the perpendicular field component in the layer of $y/T_m = 0.05$ between the main pole and the medium. The recording medium consists of Alnico 5 magnets which are arranged so as to have the easy axis of magnetization of the magnet in the perpendicular direction of medium. In this experiment, the spacing between the main pole and the medium is 1 mm, the thickness of the medium is 20 mm, and $T_m = 10$ mm. The solid and broken lines in the figure represent the magnetic field distributions normalized by the field strength at the origin in the presence and absence of the medium, respectively. In the presence of the medium, the magnetic field strength considerably increases and the field distribution becomes very sharp. This fact means that μ_{me} becomes large in the presence of the medium because of the remarkable decrease of the demagnetizing field in the main pole tip and that the sharp transition of the magnetization in the recording medium can be realized. The fact can be also ascertained by the following results.

Fig.6 is the reproduced voltage versus MMF characteristics of the actual head in the digital recording for the different recording densities. In the experiments, the main pole was a Fe-Ni electro-deposited film of thickness of 3 μm, and the recording medium was a Cr-Cr sputtered film of thickness of 0.5 μm having the perpendicular anisotropy.[7] The reproduction was made with the ring type head because of its high

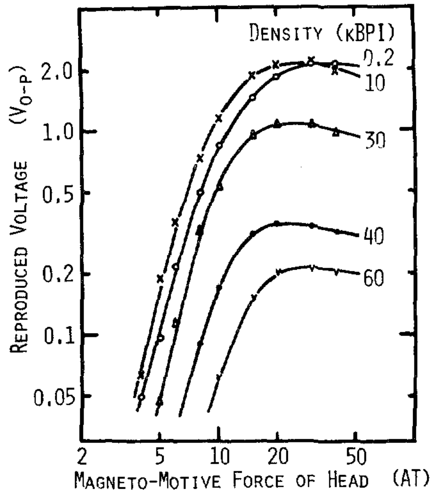

Fig.6. Reproduced voltage vs. magneto-motive force of actual head.
(T_m = 3 μm, G_{eff} = 1.08 μm, V_t = 9.5 cps)

reproducing efficiency in short wavelength. The output voltage at 60 kBPI was measured at the second peak region of the frequency response curve, because the effective gap length was larger than the wavelength of the signals.

Although the saturating magneto-motive force is about 10 times larger than the ordinary ring type head, it is clearly observed that the saturation current is nearly constant irrespective of the recording density and that the reproduced voltage scarecely drops after the saturation current in high densities. The fact means that the effect of the recording demagnetization in short wavelength is very small in the perpendicular recording and that the field distribution of the actual perpendicular recording head is very sharp and pure as expected.

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