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Analysis of Writing Characteristics of CF-SPT Head Using 3-D Read/Write Simulation System

Masaya Ohtake, Norio Takahashi, *Fellow, IEEE*, and Kiminari Shinagawa

***Abstract*—Recently, the increase of areal recording density is remarkable. In order to develop a high density recording device, a read/write (R/W) simulation using three dimensional (3-D) magnetic field analysis is indispensable. In this paper, the magnetic field in a cusp-field single-pole-type (CF-SPT) head with discrete track media is analyzed using a 3-D R/W simulation system, in which edge-based finite element method and 3-D medium hysteresis model based on the ensemble of the Stoner–Wohlfarth (SW) particles are combined. The effects of ampereturns and the discrete track media on the distribution of recorded magnetization are investigated. The detailed behavior of flux around the discrete track media and continuous media is illustrated.**

***Index Terms*—Cusp-field single-pole-type (CF-SPT) head, discrete track media, magnetic recording, medium hysteresis model, three-dimensional finite element method.**

I. INTRODUCTION

A HIGHER AREAL recording density of hard disk drive is achieved by increasing not only linear density (BPI) but also track density (TPI). Then, three-dimensional (3-D) read/write (R/W) simulation is necessary to calculate the flux distribution in the cross-track direction, because a cross-track interference in the write process becomes a serious problem for high density magnetic recording. The 3-D R/W simulation system is developed by authors [1] combining the edge-based finite element method (FEM) and the 3-D medium hysteresis model based on the ensemble of the Stoner–Wohlfarth (SW) particles. The perpendicular magnetic recording head, such as CF-SPT head [2], is expected for higher areal recording density more than several hundreds of $\mathrm{Gb/in^2}$.

In this paper, the magnetic field of cusp-field single-pole-type (CF-SPT) head recording on a discrete track medium [3] is analyzed using the 3-D R/W simulation system. The effects of ampere-turns and discrete track media on the recorded magnetization are examined. The possibility of 200 $\mathrm{Gb/in^2}$ recording is illustrated.

II. R/W SIMULATION SYSTEM USING 3-D FEM

The equation for nonlinear static magnetic field analysis using the magnetic vector potential $\boldsymbol{A}$ is given by

$$\mathrm{rot}(v\,\mathrm{rot}\boldsymbol{A}) = \boldsymbol{J}_0 + v_0\mathrm{rot}\boldsymbol{M} \tag{1}$$

where $\boldsymbol{J}_0$ is the magnetizing current density, ν is the reluctivity, ν_o is the reluctivity of vacuum, and $\boldsymbol{M}$ is the magnetization in the medium. The edge-based finite element method using a hexahedral element is applied in the magnetic field analysis. The under-relaxation iteration method is utilized for the nonlinear analysis of magnetization in the media [1].

$\boldsymbol{M}$ is computed using the medium magnetic model as the ensemble of SW particles [4]. Therefore, the intergranular exchange coupling is taken into account in the M-H characteristics. This model is assumed to consist of 512 particles having same magnetic moments. The energy E of uniaxial particle under the external field H is given by

$$E = K_\mathrm{u}V\left\{sin^2\theta - 2h\,cos(\alpha-\theta)\right\} \tag{2}$$

where K_u is the anisotropy energy constant, V is the volume of SW particle, θ is the angle from magnetic easy axes p of magnetic moment, h is the magnetic field $(\equiv H/H_k)$ normalized by the anisotropy field H_k. The anisotropy field H_k of SW particles is assumed to follow a Gaussian distribution. The direction θ of magnetic moment is determined from the energy E taking account of the history. The magnetization of the ensemble in an applied magnetic field is given by summing the magnetic moment of each SW particle.

III. CF-SPT HEAD MODEL AND ANALYSIS CONDITION

Fig. 1 shows a 1/2 region of the CF-SPT head model analyzed. The main pole and dual coils are sandwiched with two return-path yoke, then a high recording field can be produced. The opposite currents flow in two coils, and the number of turns of each coil is unity.

The head in Fig. 1 is assumed as for 200 $\mathrm{Gb/in^2}$ recording. Table I shows the specifications of the analyzed model. H_co denotes the dynamic coercivity. This is determined referring the proposal by Storage Research Consortium (SRC). The discrete track medium is used. The space t between tracks is set to 1/10 of track width Tp. The saturation flux density B_s of main pole and soft underlayer is 2.4 T, and that of return yoke is 1.4 T.

The analyzed region is subdivided into about 360 000 elements. The medium is subdivided by Tww/5 pitch in the z direction (down track direction). The coefficient of under-relaxation iteration method [1] is set to 0.02.

IV. FACTORS AFFECTING RECORDING CHARACTERISTICS

A. *Effect of Ampere-Turns*

Fig. 2 shows the flux distribution near the main pole and media. Fig. 3 shows the effect of ampere-turns on the flux density along line A-A' (down-track direction) in the medium de-

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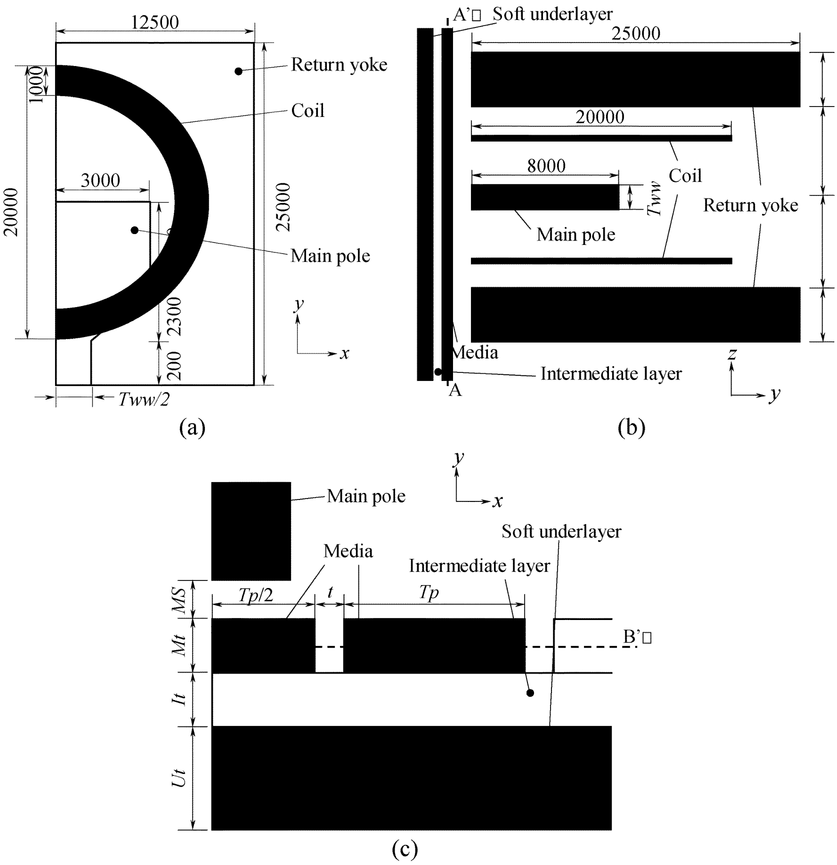


Fig. 1. CF-SPT head model (1/2 area). (a) Front view $x - y$ plane, (b) side view $y - z$ plane, (c) main pole region $x - y$ plane.

TABLE I
SPECIFICATIONS OF THE ANALYZED MODEL

Head width *Tww* (nm)	127.8
Track width *Tp* (nm)	150
Space between tracks *t* (nm)	15
Magnetic spacing *MS* (nm)	10
Thickness of recording layer *Mt* (nm)	10
Thickness of Int.layer *It* (nm)	10
Thickness of uderlayer *Ut* (nm)	100
Saturation magnetization of recording layer M_s (T)	0.565
Coercivity of recording layer H_{co} (kA/m)	637

noted in Fig. 1(b). The maximum values of flux density under the main pole at 0.05, 0.075, 0.1, and 0.2 AT are 1.08, 1.25, 1.38, and 1.55 T, respectively.

Fig. 4 shows the distribution of magnetization in the medium, and its amplitude of the y-component M_y along line B-B' (cross-track direction) denoted in Fig. 1(c) is shown in Fig. 5. The medium is not sufficiently magnetized at 0.05 AT. On the contrary, the central part of the recording track is magnetized nearly until saturation magnetization at 0.1 and 0.2 AT. The magnetization is slightly increased at the edge of the track. The cross-track interference in the write process is negligibly small. As the flux flows avoiding the edge of recording track, the magnetization in the recording track is not uniform along B-B' line.

As an example, the CPU time for the case of Fig. 3 (0.1 AT, 1 step) is about 33.5 h (computer used: Pentium 4 2.8 GHz, memory 1.5 GB).

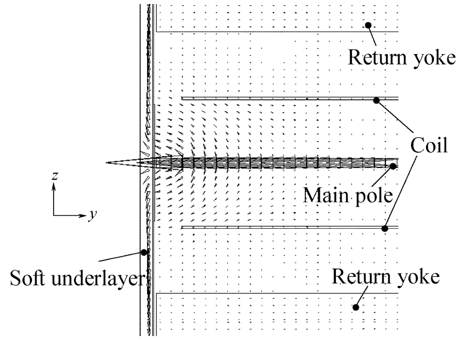


Fig. 2. Flux distribution under recording process (discrete, 0.1AT, $y - z$ plane).

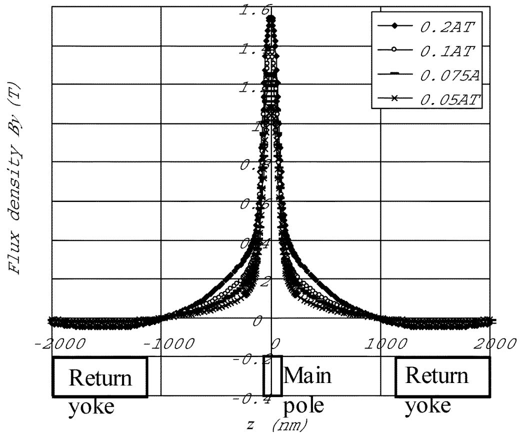
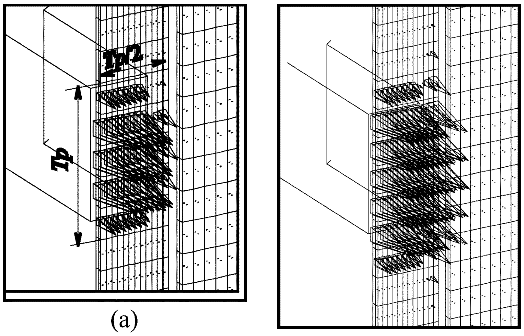


Fig. 3. Effect of ampere-turns on flux density along line A-A' (discrete).



(a) (b)

Fig. 4. Distribution of magnetization.

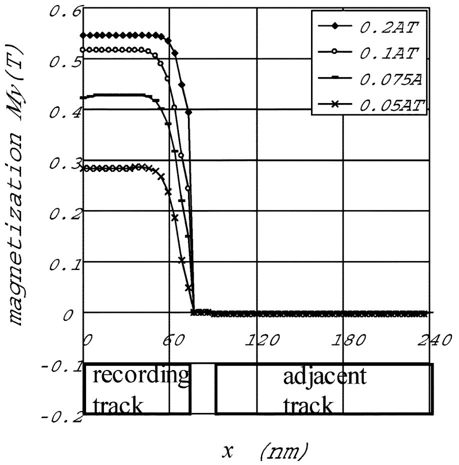


Fig. 5. Effect of ampere-turns on distribution of magnetization along line B-B' (discrete).

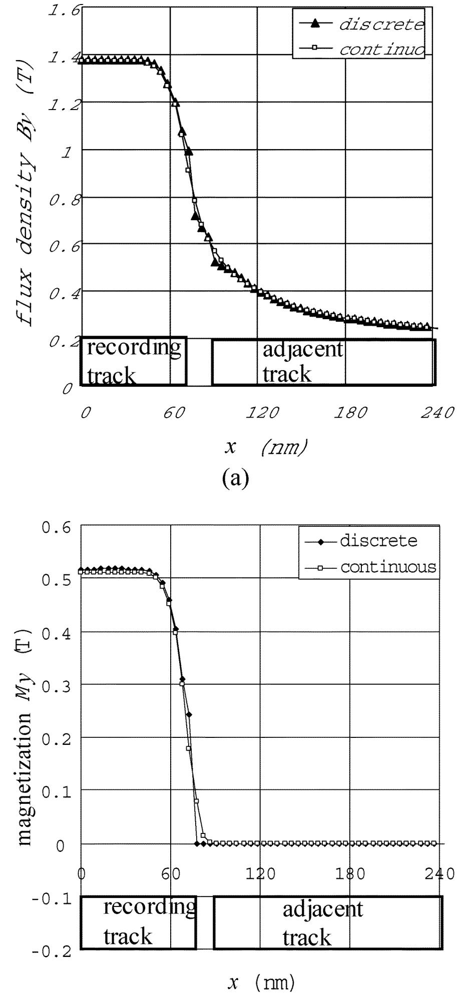
B. Effect of Discrete Track Media

The effect of discrete track media on recording characteristics is examined by comparing the flux distributions in discrete track and continuous media. Fig. 6 shows the distribution of the y components of flux density B_y and magnetization M_y along line B-B'. As the flux from the main pole spreads out in the x and z directions as an leakage flux (fringing flux) as shown in Fig. 2 in spite of the small magnetic spacing [(MS)=10 nm], B_y begins to drop at about 20% inside ($x \approx$50 nm) of main pole. The leakage flux in the adjacent track in the discrete media is almost the same with that in the continuous media. Although there exists some leakage flux in the adjacent track of both media, the cross-track interference is negligible, because the amplitude of leakage flux is not sufficiently large to magnetize the media.

V. CONCLUSION

The obtained results can be summarized as follows.

1) The detailed behavior of flux and magnetization is illustrated.
2) It is shown that the cross-track interference in the write process is negligibly small for both continuous and discrete media when the CF-SPT head denoted in the paper is used.



(a)

(b)

Fig. 6. Effect of discrete track medium on distribution of By and My along line B-B' (0.1AT). (a) Flux density By and (b) magnetization My.

The determination of the optimal construction of CF-SPT head for higher areal recording density will be possible by analyzing the detailed behavior of flux and magnetization using the 3-D R/W simulation system.

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