Media magnetization calculation using three-dimensional finite element method in perpendicular magnetic recording

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Media magnetization calculation using three-dimensional finite element method in perpendicular magnetic recording

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The magnetic medium was included into the finite element method to analyze the recording mechanism of perpendicular magnetic recording. Interactions between the head and medium were accurately considered. The effects of media properties such as the anisotropy field dispersion, the easy axis distribution, and exchange coupling strength on the recording resolution were investigated using the developed program. It was found that reducing the dispersion of anisotropy fields was the most effective way to decrease both the transition width and track width. © *2005 American Institute of Physics*. [DOI: 10.1063/1.1853273]

I. INTRODUCTION

The finite element method (FEM) is a useful technique to analyze head field distributions in perpendicular magnetic recording. Two-dimensional FEM has been used to demonstrate the advantages of a shielded structure at the trailing edge of the main pole of a single pole head (SPT).[1] The effect of properties of soft magnetic underlayer (keeper) on the head field of SPT was investigated in detail.[2] In order to increase the head field strength and improve the head field gradient, a complicated pole structure has been proposed based on the results of the three-dimensional (3D) FEM software JMAG-Studio.[3,4] On the other hand, simulations using the LLG equation have been effective when considering the media microstructure, thermal phenomena, and media noise.[5] However, it is currently difficult to analyze the whole head volume, including the complicated pole tip structure and head-media interactions with the LLG equation method. In this article a program was produced in which the media magnetization was introduced into the 3D FEM model. The head-media interactions were taken into account. The effects of media magnetic properties such as the anisotropy field dispersion, the easy axis distribution, and the exchange coupling strength on the recording resolution were investigated.

II. ANALYSIS METHOD

A. Algorithm

With regard to thermal stability and saturation recording in perpendicular media, thicker media are preferable. When the media are relatively thick the magnetic particles switch incoherently, resulting in a smaller coercivity. In this calculation, the magnetic particles of the medium were assumed to reverse their magnetization according to the curling model. The anisotropy fields and easy axes of the magnetic particles were assumed to obey normal distributions. Exchange coupling was taken into account by a mean-field coefficient (normalized exchange field) which was defined as the ratio of the exchange coupling field, $H_{exchange}$, to the anisotropy field, H_k. Each element of the medium in the FEM model was considered to be an assembly of magnetic particles for which the mean value of magnetization was calculated.

Figure 1 shows the general flow chart of the 3D FEM JMAG-Studio program, combined with the magnetization calculation. User subroutines were used to introduce the medium magnetization into the FEM model; hsusrl.f for the initialization of the curling mode and distribution of anisotropy fields, magusr.f for the medium magnetization calculation and hsusr3.f for the medium movement.

B. Head-medium interaction

As shown in Fig. 1, after each iteration the medium magnetization was fed back into the FEM model. From this, a

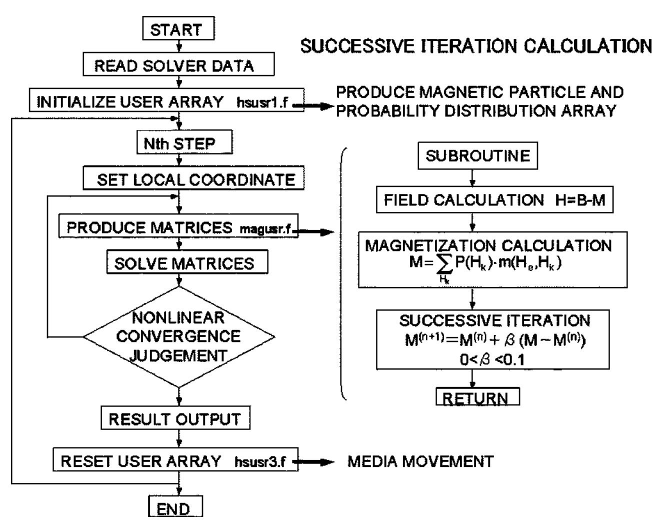

FIG. 1. General flow chart of JMAG-Studio combined with the media magnetization calculation.

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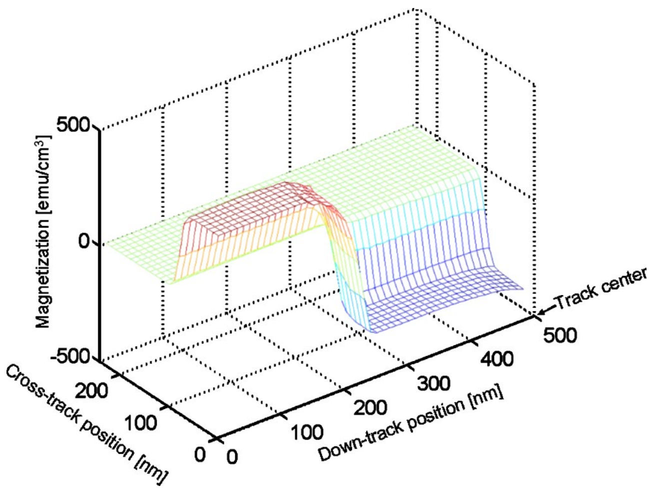

FIG. 2. Isolated magnetization transition when head-medium interactions are ignored.

flux density and head field were obtained for the next iteration. In this way, head and medium interactions were considered. Figures 2 and 3 show examples of calculated isolated magnetization transitions when head-medium interactions were ignored and considered, respectively. "Ignored" means that the head field was constant, whereas "considered" means that the head field varied according to the media magnetization in the iteration calculation. It can be seen that the transition became sharper in the down-track direction, and the track edge became narrower in the cross-track direction when head-medium interactions were considered. Also, enhancement of the magnetization at the track edges and at the position immediately following the transition was observed due to the demagnetization effect.

Using the three-dimensional reproducing sensitivity function of a giant magneto resistance head with a shield gap of 60 nm, the reproduced voltage wave form was calculated by reciprocity. Figure 4 shows the normalized reproduced wave forms. T_{50}, which is the width of the output waveform at 50% level, was measured as shown in the figure. When head-medium interactions were considered, the maximum

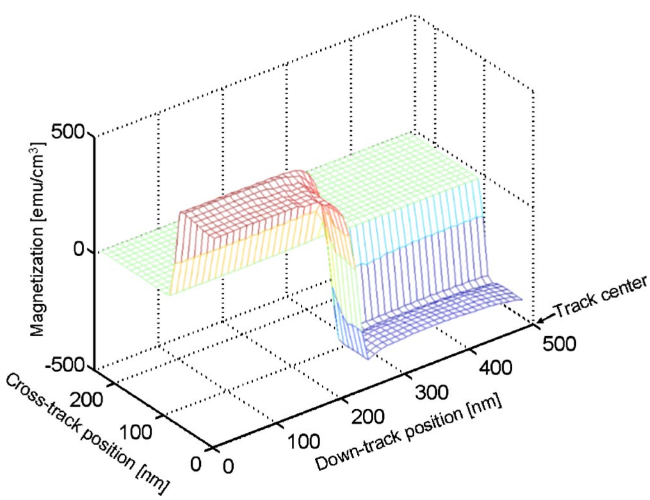

FIG. 3. Isolated magnetization transition when head-medium interactions are considered.

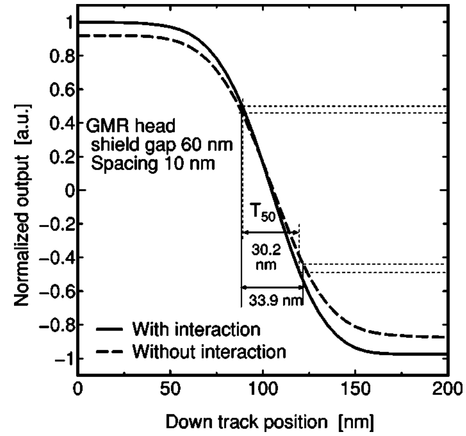

FIG. 4. Comparison of reproduced wave forms using the recorded magnetization when the head-medium interactions are considered or ignored.

output and T_{50} increased by 9.1% and decreased by 10.9%, respectively, compared with the ignored case. This indicates the importance of considering head-medium interactions when simulating recording in SPT head and double layer perpendicular media.

III. RESULTS AND DISCUSSIONS

Table I lists the calculation conditions. The track width of the write head was 150 nm. The coil had one turn and the direct current flowing into the coil element was set as 0.1 A, i.e., the magnetomotive force (MMF) was 0.1 A T (0 peak). Assuming an initial ac demagnetized state, isolated magnetization transitions were calculated under different conditions.[6] X_{50} was defined as the down-track distance along the track center between the points where the magnetization was ±50% of saturation. T_{w50} was defined as the cross-track distance between the points where the magnetization dropped to 50% of the value at the track center.

Figure 5 shows the dependence of the transition width X_{50} and track width T_{w50} on the standard deviation of anisotropy field strengths. The standard deviations of the anisotropy field are normalized to the mean value of 15 kOe. On

TABLE I. Conditions used in the calculation.

Write head	
Main pole thickness T_m	400 nm
Main pole width T_w	150 nm
B_s of main pole material	24 kG
Initial permeability of main pole material	2000
Head-medium spacing	10 nm
Recording layer	
Thickness	10 nm
Anisotropy field	15 kOe
Saturation magnetization	500 emu/cm^3
Coercivity	5 kOe
Seed layer	10 nm
Soft magnetic underlayer (SUL)	
Thickness	300 nm
B_s of SUL	20 kG
Initial permeability of SUL	1500
MMF	0.1 A T

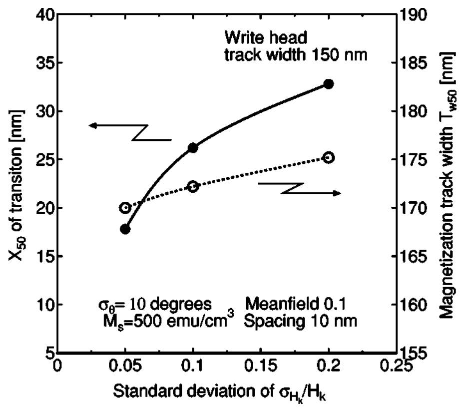

FIG. 5. Dependence of transition width and track width on anisotropy field dispersion.

decreasing σ_{Hk}/H_k, both the transition width and track width decreased monotonously. When σ_{Hk}/H_k decreased from 0.2 to 0.05, X_{50} and T_{w50} decreased from 32.5 to 17.8 nm, and from 175.2 to 170.0 nm, respectively.

Figure 6 shows the dependence of the transition width and track width on the standard deviation of easy axes dispersion, which was set at 20, 10, and 5 deg. On decreasing σ_θ, X_{50}, and T_{w50} decreased monotonously, the same as the dependence on σ_{Hk}/H_k. When σ_θ was decreased from 20 to 5 deg, X_{50} and T_{w50} decreased from 30.0 to 26.1 nm, and from 172.4 to 171.6 nm, respectively. The effect of the easy axes dispersion on the transition width and track edge is less than the dispersion of anisotropy field strength.

Figure 7 shows the results for various mean-field coefficients. When the mean-field coefficient was increased from 0.0 to 0.3, X_{50} decreased from 34.2 to 18.2 nm, while T_{w50} increased from 169.4 to 178.8 nm. When stronger exchange coupling exists, particles will reverse their magnetization together, therefore a sharper transition can be obtained. Furthermore, stronger exchange coupling increases the magnetic cluster size, resulting in a wider written track, this result agrees with that by Shukh.[7]

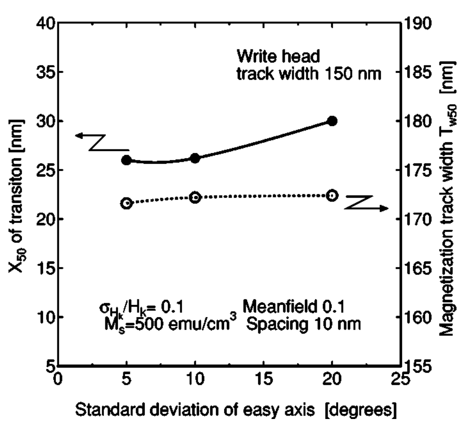

FIG. 6. Dependence of transition width and track width on easy axis dispersion.

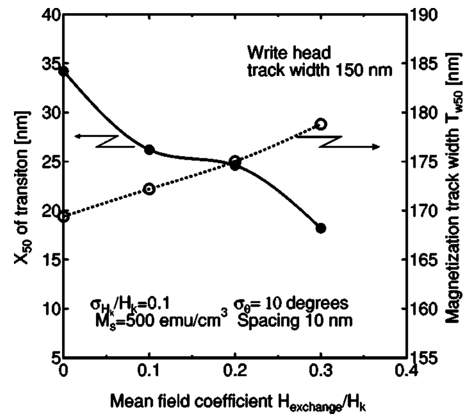

FIG. 7. Dependence of transition width and track width on mean-field coefficient.

IV. CONCLUSION

In this article, a program was produced by introducing medium magnetization into a 3D FEM model. Using this program, the effects of anisotropy field dispersions, easy axes dispersions and mean-field coefficient on the recording resolution were investigated. It was shown that the effect of the anisotropy field dispersion was the greatest among the three parameters. Therefore, control of it is an indispensable condition for achieving high density recording in the single pole head and double layer perpendicular magnetic medium system.

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