Nonlinear Eddy Current Analyses of Magnetic Recording Write Heads by FEM in Three Dimensions

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Abstract. The electromagnetic field analyses of thin-film write heads are carried out by using the finite-element method with the material nonlinearity and eddy current taken into account. By using the calculated results, criterion for the yoke material at the recording frequency is discussed. It is also shown that the 3D calculations are indispensable in optimizing both the write head geometry and material for high density and high frequency recordings.

1. Introduction

The magnetic recording density increases by the ratio of 60% a year in recent years and the areal density of commercial hard disk drive has reached 5 Gb/in\(^2\) (giga bits per square inch). The roadmap shows that hard disk drive with the areal density of 20 Gb/in\(^2\) will be on the market in 2001 and 80 Gb/in\(^2\) in 2005. In order to achieve high transfer rate, recording frequency is expected be 350 MHz for 20 Gb/in\(^2\) and 700 MHz for 80 Gb/in\(^2\). In this situation, spin-valve magnetoresistive read head has already been developed, while write head has rarely been discussed. Therefore, it is necessary to understand the recording performance of write head in the recording frequency range of several hundred megahertz.

In this paper, the electromagnetic field analyses of thin-film write heads are carried out by using the finite-element method with the material nonlinearity and eddy current taken into account [1], where the FEM commercial software [2] is used. Analyzed head is assumed to be used for 20 Gb/in\(^2\) recordings. First, the finite-element modeling is validated by using three different meshes. Then, transient recording field is shown for trapezoidal current of 500 MHz. Also, recording field on yoke structure is discussed and it is shown the use of high magnetization layer for upper yoke has an advantage in gaining a larger recording field. Recording field strength on recording frequency is shown for various core materials. Interestingly enough, the recording field strength does not decrease significantly when the recording frequency becomes higher, which is quite different from the results obtained by 2D calculations [3]. In order to understand the phenomena better, the recording field strength vs. frequency strained from the head for 2 Gb/in\(^2\) recordings is derived and found that the recording field strength drops very quickly as the frequency becomes higher. The major difference of 20 Gb/in\(^2\) and 2 Gb/in\(^2\) heads is geometrical dimensions, especially the yoke length. Finally, it is shown that the 3D calculations are indispensable in designing the write head geometry and in choosing the yoke material for high density and high frequency recordings.

2. Description of Calculated Model

Analyzed head is assumed to be used for 20 Gb/in\(^2\) (giga bits per square inch) recordings and the dimensions are: gap length \(G = 0.3 \, \mu\text{m}\); track width \(T_w = 0.45 \, \mu\text{m}\) with trimmed
lower yoke; throat height \(G_y = 0.5 \ \mu m\); upper core thickness \(t_u = 4.0 \ \mu m\); and lower yoke thickness \(t_l = 3.0 \ \mu m\). Taking the advantage of symmetry, half the region including thin-film write head is divided into 193,256 tetrahedra with 33,118 nodes. In addition to this finite-element mesh (mesh A, hereafter), we have used two other meshes 203,349 elements with 34,873 nodes (mesh B) and 277,405 elements with 42,279 nodes (mesh C) to validate the modeling. For mesh A we have not modeled neither upper nor lower yokes after contact; neglected upper yoke after contact for mesh B. In mesh C whole yoke has modeled. In Fig. 1, mesh B, the model with upper yoke after contact is not modeled, is shown. I can be seen from the figure that the upper and lower yokes are divided into 7 layers. Four materials (Ni_{80}Fe_{20}, Ni_{50}Fe_{50}, Ni_{45}Fe_{55} and ultimate, which has yet to have been developed) are assumed for the calculations. Their saturation flux density \(B_s\), and conductivity \(\sigma\) are: 1.0 T and \(5.0 \times 10^6 \ \text{S/m}\) for \(\text{Ni}_{50}\text{Fe}_{50}\); 1.4 T and \(2.5 \times 10^6 \ \text{S/m}\) for \(\text{Ni}_{50}\text{Fe}_{50}\); 1.6 T and \(2.0 \times 10^6 \ \text{S/m}\) for \(\text{Ni}_{45}\text{Fe}_{55}\); and 2.0 T and \(5.0 \times 10^5 \ \text{S/m}\) for ultimate.

3. Analyzed Method

The electromagnetic field analyses of thin-film write heads are carried out by using the finite-element method with the material nonlinearity and eddy current taken into account [1]. We have used FEM commercial software [2]. In the software the \(A-\phi\) (magnetic vector potential - electric scalar potential) method is used, namely, the governing equations

\[
\nabla (\frac{1}{\mu} \nabla A) = J_e - \sigma (\frac{\partial A}{\partial t} + \nabla \phi) \quad \text{and} \quad \nabla \cdot \left( - \sigma (\frac{\partial A}{\partial t} + \nabla \phi) \right) = 0
\]

are solved. In (1), \(\mu, A, J_e, \sigma\) and \(\phi\) are, respectively, permeability, magnetic vector potential, current density, conductivity and electric scalar potential. Edge-based first order tetrahedral elements are used in order to divide the whole region.

4. Calculated Results and Discussion

Fig. 2 shows the calculated recording head field at the track center for a spacing of 30 manometers along with the trapezoidal recording current of 500 MHz. In the calculation, \(\text{Ni}_{50}\text{Fe}_{50}\) is assumed for the yoke material. As can be seen from the figure, the delay of recording field with respect to the current is found. Note here that a notable difference can not be found between the results by using meshes A, B and C. Because the calculation times for mesh A, B and C are approximately 760 min., 775 min. and 1195 min. on
Fig. 2 Recording field vs. time for 500 MHz trapezoidal current.

Fig. 3 Recording field vs. time for various head structure, where 400MHz trapezoidal current was applied. Case 1: all Ni<sub>43</sub>Fe<sub>57</sub> yoke, case 2: upper 0.8 μm Ni<sub>43</sub>Fe<sub>57</sub> film, case 3: upper 0.8 μm and lower 0.2 μm Ni<sub>43</sub>Fe<sub>57</sub> films, case 4: upper 0.8 μm and lower 0.2 μm Ni<sub>43</sub>Fe<sub>57</sub> films, case 5: all Ni<sub>43</sub>Fe<sub>57</sub> yoke

Fig. 4 Recording field strength on recording frequency, where MMF = 0.45 AT.

A pentium II (450MHz) computer, using mesh A is preferable. Because high contain ratio of Fe leads to chemical instability or high magnetostriction,
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In Fig. 3, calculated recording fields vs. time are shown, where trapezoidal current of 400 MHz is applied. In the calculation, thin Ni_{45}Fe_{55} layers are assumed on the gap side and Ni_{40}Fe_{20} is used for the rest of the yoke. From the same figure, the use of Ni_{40}Fe_{55} layer for upper yoke has an advantage in gaining a larger recording field.

In Fig. 4, recording field strength on recording frequency is shown for various core materials, where MMF = 0.45 AT. Recording field strength requires 1.5 times of media coercivity at the frequency, therefore, criterion for the yoke material can be found from the same figure. Interestingly enough, the field strength does not decrease significantly when the recording frequency becomes larger, which is quite different from the results obtained by 2D calculations [3]. In order to understand the phenomena better, the recording field strengths vs. frequency strayed from the head for 2 Gb/in^2 recordings are shown in Fig. 5, where Ni_{40}Fe_{20} is assumed as the yoke material. From the figure it can be seen that the recording field strength drops very quickly as the frequency becomes higher. The main difference of 20 Gb/in^2 and 2 Gb/in^2 heads are geometrical dimensions, especially the yoke lengths. Therefore, it is very important to optimize the geometry. Also, 3D calculations are indispensable in designing a write head for high density and high frequency recordings.

5. Conclusion

The electromagnetic field analyses of thin-film write heads are carried out by using the finite-element method with the material nonlinearity and eddy current taken into account. By using the calculated results, criterion for the yoke material at the recording frequency is discussed. It is also shown that the 3D calculations are indispensable in designing both the write head geometry and material for high density and high frequency recordings.

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