Micromagnetic Simulations of Recording Write Heads – A Comparison of Various Micromagnetic Software -

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Abstract — We compared the performance of three micromagnetic software: (a) originally developed by Hitachi and refined at Kogakuin Univ. and Niigata Institute of Technology, (b) developed by Fujitsu, and (c) *Magpar* a free, public domain program. We modeled a perpendicular write head to compare the performance of the software. It was found that the finite-difference method based micromagnetic software, (a), had difficulties with complex structures but required less RAM, while finite-element, boundary integral method based micromagnetic software, (b) and (c), could handle complex structures but required more RAM.

I. Introduction

Micromagnetic analysis is a useful tool to simulate recording phenomena, which occur in nanometer-sized regions and on sub-nanosecond time-scales. The difficulty is that the computation time can be long for large, complex structures, therefore, applications have been limited to the analysis of recording media or simple-structured objects. It is also very difficult to validate the simulation results with experiments. Therefore, "µMAG Standard Problem #4 [1]" has been used to validate the software. With regard to the write head analysis, large scale micromagnetic analysis was not practical until the development of finite-element based techniques [2], due to the multi-scale nature of the problem, i.e., a nanometer resolution is required compared with the very large overall dimensions of some tens of micrometers. Moreover, a standard problem for write heads has not been developed.

In this paper, we compare the performance of three micromagnetic software, (a) a program originally developed by Hitachi and improved at Kogakuin Univ. and Niigata Institute of Technology (NIIT) [3], (b) a program developed by Fujitsu [4], and (c) the public domain program *Magpar* ver. 0.9 [2]. These are referred to as *LLG-NIIT*, *LLG-Fujitsu* and *Magpar* throughout this paper. *LLG-NIIT* is based on the finite-difference method (FDM) to discretize the three-dimensional (3D) space, *LLG-Fujitsu* and *Magpar* use the FEM and boundary integral method (BIM). We have assumed a single-pole-type (SPT) perpendicular write head with a trailing shield to compare the performance of the software. We have derived the quasi-static recording field distribution and the dynamic recording field response to a high-frequency current. FDM-based micromagnetic software, *LLG-NIIT*, has difficulties with complex structures, e.g. trapezoidal pole tips, and calculations take longer, but require less RAM. It is also difficult to obtain a high resolution when regular FDM cubic cells are used. Conversely, FEM-BIM micromagnetic software, *LLG-Fujitsu* and *Magpar*, can handle complex structures and the calculations are fast, but a large amount of RAM is required. The mesh size vs. accuracy is also discussed for FDM-based software.

II. Recording Write Head Model [3]

The SPT head model shown in Fig. 1 was used. The head had a trailing shield placed 60 nm from the main pole. The material characteristics are shown in Table I, where M_s is the saturation magnetization, K_u the anisotropy energy, A the exchange constant and α the Gilbert damping factor. For both the head and media soft underlayer (SUL), the anisotropy direction was assumed to be the cross-track ($+y$) direction. The recording layer was assumed to be air. The model dimensions were similar to those of commercial heads, except that the main pole tip had a larger area with a throat height of 200 nm and a neck height of 200 nm. With regard to the air-bearing surface (ABS) of the main pole, a 160 nm wide × 260 nm long rectangle was used for *LLG-NIIT* and *Magpar*, while a trapezoid, with a width of 80 - 150 nm and a length of 250 nm, was used for *LLG-Fujitsu*. The recording field distributions were observed 28 nm from the air-bearing surface (ABS) and the distance between the ABS and SUL was 66 nm. Note that the head dimensions of the pole tip were not intended to be leading-edge designs, but were chosen to enable a comparison of the software performance, i.e., a 20-nm-cell FDM model was sufficient to reproduce the recording phenomena.

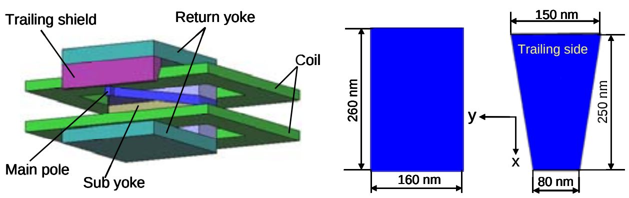

Fig. 1. Perpendicular write head model used for the comparison. (a) Bird's eye view, (b) rectangular and (c) trapezoidal main pole tips.

TABLE I
MATERIAL CHARACTERISTICS FOR HEAD AND SOFT UNDERLAYER

	SPT head	Soft underlayer
M_s emu/cm^3	1910	955
($4\pi M_s$ kG)	24	12
K_u erg/cm^3	3x10^4	3x10^4
A erg/cm	1x10^{-6}	1x10^{-6}
α	0.2	0.2

The micromagnetic Landau-Lifshitz-Gilbert (LLG) equation,

$$(1+\alpha^2)\dot{\boldsymbol{M}} = -|\nu|\boldsymbol{M}\times\boldsymbol{H} - \frac{|\nu|\alpha}{M_s}\boldsymbol{M}\times(\boldsymbol{M}\times\boldsymbol{H}) \qquad (1)$$

was for all the magnetic material, where $\boldsymbol{M}$ is the magnetization vector, $\boldsymbol{H}$ is the effective field vector and ν is the gyromagnetic constant.

III. Results and Discussion

In Fig. 2, the static recording fields are compared along with a result obtained by a FEM solution of Maxwell's equations (Maxwell-FEM). *LLG-Fujitsu* gave a rather small recording field due to the smaller ABS area. Maxwell-FEM gave insight but was not able to accurately simulate the magnetization in the main pole tip. *Magpar* showed the largest field strength, and *LLG-NIIT* was in between *Magpar* and *LLG-Fujitsu*.

In Fig. 3, the responses to a high-frequency recording current are shown. *LLG-NIIT* showed a somewhat bumpy response compared with *LLG-Fujitsu* and *Magpar*, but there was no major difference in response times among the three models. With regard to the peak field values, *LLG-NIIT* and *Magpar* were similar and *LLG-Fujitsu* was smaller due to the trapezoidal pole tip. The difference was not remarkable because reaching the maximum value requires more than 1 nanosecond. In Table II, the calculation times (wall-clock times) and RAM required are summarized for the dynamic calculations, showing that the FDM-based micromagnetic software, *LLG-NIIT* takes longer, but requires smaller RAM. For the FEM-BIM micromagnetic software, *LLG-Fujitsu* and *Magpar*, the calculation time is short considering the mesh size, but the RAM required is large.

We compared the accuracy vs. cell size for the FDM-based micromagnetic software, *LLG-NIIT*, as shown in Fig. 4. In addition to the 20-nm cell model, we used 10-nm cells to discretize the whole area, with a total cell count of 30,965,952. In the calculations, the initial state was set when the driving current was at the negative peak. We also assumed antiferromagnetic coupling (AFC) in the SUL for practical reasons. As can be seen from Fig. 4, there were more bumps in 20-nm model but we did not find a major difference in the response. For the 10-nm cell model, the calculation time and RAM required were 64.5 hours and 36.6 GB, respectively on an AMD Opteron 6174 computer (2.2 GHz, 48 cores). Some other important results, e.g. dynamic magnetization rotation will be compared in the full paper.

IV. References

[1] μMAG Standard Problem #4, [Online]. Available: http://www.ctcms.nist.gov/~rdm/std4/ spec4.html

[2] Magpar, [Online]. Available: http://www.magpar.net/FrontPage

[3] Y. Kanai, K. Koyama, M. Ueki, T. Tsukamoto, K. Yoshida, S. J. Greaves, and H. Muraoka, "Micromagnetic analysis of a shielded write head using symmetric multiprocessing systems," *IEEE Trans. on Magn.*, vol. 46, no. 8, pp. 3337-3340, Aug. 2010.

[4] Fujitsu, micromagnetic software, [Online]. Available: http://img.jp. fujitsu.com/downloads/jp/jmag/vol55-3/paper09.pdf (in Japanese).

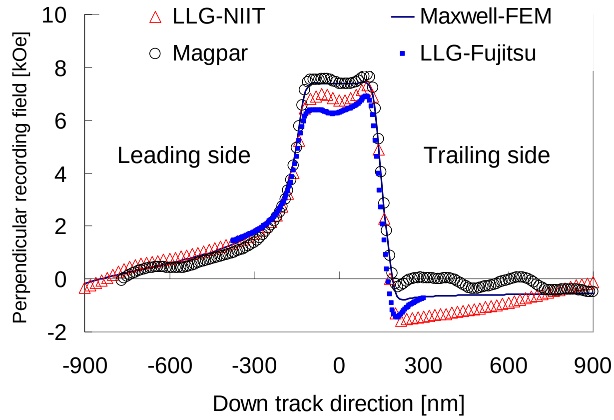

Fig. 2. Comparison of quasi-static recording fields.

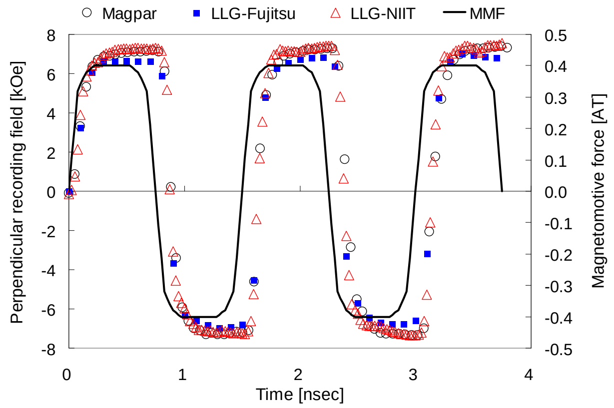

Fig. 3. Perpendicular recording field responses to the high-frequency current of 667 MHz.

TABLE II
COMPUTATION TIME AND RAM REQUIRED FOR VARIOUS SOFTWARE

	LLG-NIIT	LLG-Fujitsu	Magpar
Formulation	FDM	FEM-BIM	FEM-BIM
Number of elements	3,870,744	2,400,000	602,110
Element type	Brick	Tetrahedron	Tetrahedron
Pole tip	Square	Trapezoidal	Square
Calculation time	9.5 hours	20 hours	6.9 hours
RAM required	4.4 GB	78 GB	19 GB
CPU	Core i7 Extreme	Xeon	Core i7 950
Number of cores	6 (6 × 1)	32 (2 × 16)	8 (4 × 2)
CPU clock	3.33 GHz	3.60 GHz	3.06 GHz

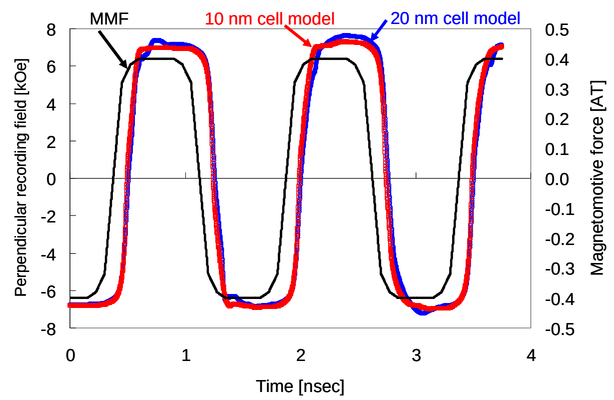

Fig. 4. Perpendicular recording field responses to the high-frequency current of 667 MHz. Comparison of 10-nm and 20-nm cell models calculated by *LLG-NIIT*. Time increments were 1 ps for both models.