Evaluation of an electromagnetic microactuator using scanning Hall probe microscopy measurements

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Scanning Hall probe microscopy (SHPM) was used to evaluate integrated magnetic microactuators designed for hard disk drives. The Hall probe measurements of the generated magnetic field strength as a function of the applied current or distance were compared to results of a finite element method simulation. The SHPM measurements and simulation results are in good agreement, confirming that simulations supported by SHPM measurements can be used successfully to predict the performance of microactuators. © *2009 American Institute of Physics*. [DOI: 10.1063/1.3077215]

I. INTRODUCTION

A proven approach for designing actuators based on microelectromagnets is to fabricate the micromagnetics (containing the stator) and the micromechanics (containing the traveler with flux closure, suspended on silicon springs) on separate wafers. For such a system, an evaluation of the magnetic force generated by the stator cannot be performed until the magnetic and mechanical parts are assembled. One approach for predicting the characteristics of the magnetic parts before assembly is based on measurements of the magnetic field strength and a comparison of the measured results with simulations. This method was applied to evaluate the stator of a slider with an integrated microactuator (SLIM) intended for an application in hard disk drives. The magnetic field created by the stator poles was measured by scanning Hall probe microscopy (SHPM) as a function of the current flowing through the coils and the distance from the actuator pole.

SHPM is an ideal technique for measuring fields above micromagnetic devices, as it combines high spatial resolution with excellent magnetic field sensitivity.[1,2] In our SHPM experiments, a micron-scale Hall sensor is scanned in a plane above the stator poles, allowing high-resolution images of the absolute field distribution above the poles to be produced. In this paper we report results of both SHPM measurements and micromagnetic simulations, and find generally good agreement between the two.

Since the magnetic actuators may have complicated shapes, the model used in the simulations must be correct in order that the actuator's performance be accurately predicted. Using SHPM to measure the strength of the field generated by the microactuator, and comparing these measurements directly with the results of simulations, can provide important verification that the model used is correct.

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II. MAGNETIC MICROACTUATOR

The concept of a SILM has been recently reported by Gatzen *et al.*[3] and Dinulovic *et al.*[4] In this design, a pair of magnetic microactuators is integrated into the slider, allowing flying height adjustment over a rotating hard disk by movement in the vertical direction, as well as a second stage actuation by movement in the lateral direction.

The magnetic microactuator consists of a U-shaped Permalloy magnetic core and two double-layered spiral copper coils for excitation of the system. The coil system features five turns per coil layer. A Permalloy with a composition of 45% nickel and 55% iron (NiFe45/55) was used for the fabrication of the magnetic microactuator due to its high magnetic saturation flux density of 1.6 T and high permeability.[5] The microactuator was fabricated using high aspect ratio microstructure technology, which combines UV depth lithography and electroplating. Both the magnetic core and the excitation coils were fabricated using electroplating. All actuator structures were embedded in the SU-8™ epoxy based resist. The silicon nitride insulation between coil layers was deposited using plasma enhanced chemical vapor deposition.[6] The total size of one magnetic actuator is 438 μm $\times$ 282 μm $\times$ 61 μm ($L \times W \times H$). The devices were found to have an electrical resistance between and 1.8 and 2.2 Ω.

III. FINITE ELEMENT METHOD SIMULATIONS

Finite element method (FEM) simulations using ANSYS™ software were carried out in order to design the magnetic microactuator and to characterize their performance. For designing the device, the behavior of the two magnetic circuits, each consisting of a stator core, stator coils, and traveler flux guide, was analyzed. However, during SHPM measurements the flux closure by the traveler was not present. Therefore, to allow a comparison, a stator simulation with only air above the poles was conducted.

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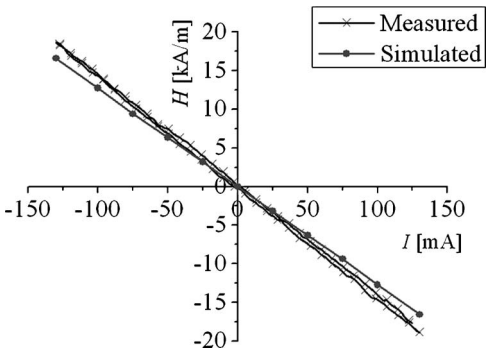


FIG. 1. Comparison of the measured and simulated magnetic field strengths 8 μm above a magnetic pole for different excitation currents up to 130 mA.

For the magnetic field calculation, three-dimensional FEM simulations were performed. For modeling the magnetic actuator, the near field element type solid 96 was used. The air environment was modeled using near field element type solid 98. The far field elements were not applied since there was a sufficient air environment surrounding the magnetic actuator. An important parameter in our simulations is the relative magnetic permeability of the soft Permalloy NiFe45/55. The magnetic permeability of a magnetic core is dependent on its size, with the permeability decreasing as the device size is increased. The core is also subjected to a demagnetizing field.[7] The relative magnetic permeability of the magnetic core and pole structures are determined using vibrating sample magnetometer (VSM) measurements. After VSM measurements, the correction of the permeability due to demagnetizing fields is performed. In this way, an average value of the magnetic permeability is developed for use in the simulation. Thus, for 20 μm thin magnetic core a permeability of 200 was used, while for 40 μm thin magnetic poles we used a permeability of 80.

IV. THE SCANNING HALL PROBE MICROSCOPE

The scanning Hall probe microscope uses a Hall sensor wet etched into a GaAs/AlGaAs heterojunction. The active area of the sensor was approximately 1.2 μm $\times$ 1.2 μm, which sets the spatial resolution of the images. The probe could be scanned over an area of several millimeters on a side. Because the Hall probe is sensitive only to the component of the field that is perpendicular to the scan plane, all magnetic field results reported here refer only to the z-component of the field. The sensitivity of the probe is about 0.4 mT.

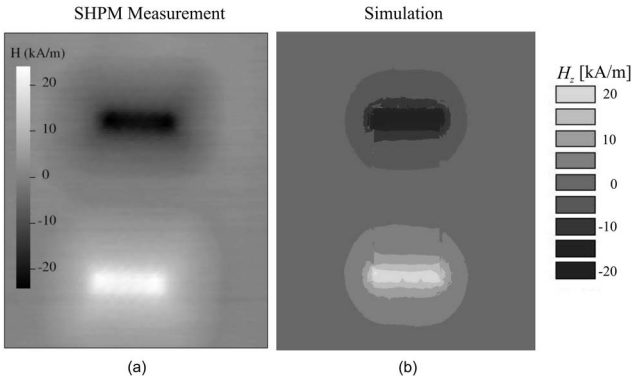


FIG. 2. The measured (a) and simulated (b) magnetic field strengths 8 μm above the magnetic poles for an excitation current of 130 mA. The center-to-center distance between the poles is 220 μm.

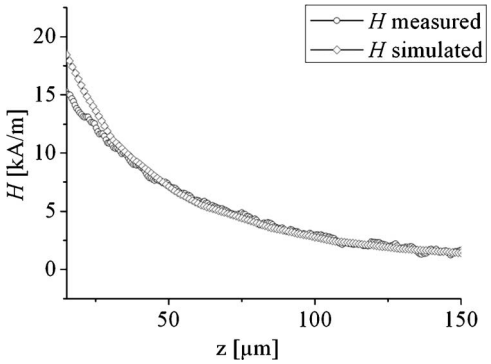


FIG. 3. Comparison of the measured and simulated magnetic field strengths as a function of the distances above a magnetic pole for excitation current of 130 mA.

V. RESULTS

Figure 1 shows the measured and simulated magnetic field strengths at a distance of 8 μm directly above one pole, as a function of the coil excitation current. Both curves are quite linear, and we see that the measured field whether the current was swept up or down. The small difference observed between the up and the down sweeps was consistent with a slow drift in the Hall probe voltage with time, and it is likely that the actual hysteresis is smaller than the measurement noise.

Figure 2 shows measured and simulated magnetic images taken in a plane 8 μm above the poles at an excitation current of 130 mA. The opposite sense of the pole magnetization can be clearly seen. In the measurements [see Fig. 2(a)], the weak field due to the wire connecting the coils can just be made out. Overall, there is good agreement between the measurements and simulations. However, a close inspection shows that the magnitudes of the maximum and minimum fields are not quite equal.

To better understand this discrepancy, in Fig. 3 we show the magnetic field at a point centered over the positive pole as a function of the height z above the pole. For z greater than about 50 μm, the agreement between the measured and

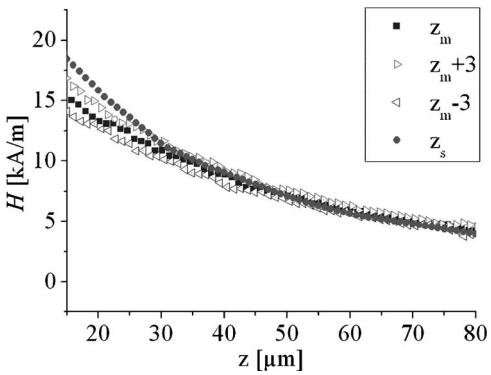


FIG. 4. Measured result with measurement distance accuracy of ± 3 μm and simulated result.

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simulated values is excellent. However, a small difference of about 20% develops at the smallest values of z. After that, both curves are almost identical. However, in the development of Micro ELectro-mechanical Systems (MEMS) devices, die simulation results, when compared with measurements on real microdevices, typically show a discrepancy of 20%–30%.[8] Furthermore, the accuracy of SHPM positioning system is taken into account. The distance between SHPM sensor and actuator is measured with an accuracy of ± 3 μm. Figure 4 shows comparison between experimental data and simulated results with 3 μm accuracy taking into account. This discrepancy might be explained by imperfection in the shape of the poles which would reduce the z component of the magnetic field.

VI. CONCLUSION

Using FEM simulations, magnetic properties of a magnetic microactuator were calculated and compared with magnetic field SHPM measurements. The simulation results are in good agreement with the measurements. This confirms that the approach using SHPM can be used successfully for the prediction of microactuator capabilities by complex MEMS devices.

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