Operating Range Optimization of a MEMS Type Slider with an Integrated Microactuator (SLIM) for Second Stage Actuation in Hard Disk Drives

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The paper describes the tests performed to determine the characteristics of four various leaf springs, as well as the evaluation of the mounting platform/chiplet motion as a function of the excitation current. For the leaf spring evaluation, a nanoindenter (Hysitron Tribo Indenter) was used. To determine the variation of the air gap as a function of the excitation current, optical microscopy as well as Laser Doppler Vibrometry (LDV) was applied.

***Index Terms*— Hard disk drive, second stage track following, flying height adjustment, electromagnetic microactuator**

I. Introduction

A slider with an integrated microactuator (SLIM) was devised whose size follows a pico slider format [1, 2]. SLIM not only provides a second stage actuation but also allows to adjusting the head-to-disk spacing of the read-write element. This way, it combines track following capabilities [4, 5] with flying height adjustment capabilities [3] typically pursued separately. SLIM is designed as a Micro Electro-mechanical System (MEMS) with a micromagnetics and a micromechanics part fabricated on two separate wafers. The micromagnetics system consists of a pair of integrated electromagnetic microactuators, and the micromechanics of a mounting platform (including a flux closure) suspended on a pair of leaf springs attached to a base. A spacer joins the slider micromagnetics and micromechanics. Figure 1 shows a SLIM test sample mounted on a flexure and used for static tests. The mounting platform carries a chiplet on which ultimately the read-write element will reside on. The SLIM system specification requires to enabling a lateral movement of the chiplet of ±625 nm (corresponding to ±5 tracks at 200 ktpi) and results in a maximal rotation of 0.18°. Due to the small rotational angle, a maximal rotation results in a flying height change of only 1 nm.

FIG. 1 HERE

There are two challenges related to such a system. One is, that the magnetic force curve is highly nonlinear and progressive for the air gap approaching zero. The other is, that stable operating conditions may only be achieved if the slope of the spring constant is greater than the one of the magnetic force curve. These two conditions ultimately define the system's operating range. Within this range, the system's magneto-mechanical operation has to allow: (1) a reduction in air gap to facilitate the flying height adjustment, (2) a change in the air gap (at one side a reduction and at the other an increase or vice versa) to accomplish the desired chiplet rotation for track following, and (3) the assembly and mounting tolerances have to be accounted for. While there are no constraints on (1) the air gap reduction for flying height control (this dimension ultimately may be chosen arbitrarily), (2) the required air gap variation for chiplet rotation is ±1.5 µm, and (3) the minimal mounting tolerance is ±1 µm for the spacer thickness variation and another ±1 µm for the chiplet height adjustment. The greatest tolerance is caused by the Si leaf springs thickness variation which follows a cube function.

II. Theoretical Considerations

A. Boundary Conditions

To find an optimal operating range, experimental investigations were carried out. For the tests, SLIM devices consisting of functional micromagnetics, a spacer, functional micromechanics, and (whenever necessary) a chiplet were prepared as test specimen.

While there was only one type of micromagnetics that entered the tests [2], a matrix of leaf springs was used in the micromechanics, with the leaf springs varying in thickness (5 µm and 15 µm) and width (100 µm and 150 µm). The thickness is the most important parameter that affects the spring stiffness, since the relationship between the two follows a cube function. Therefore, the leaf springs with two different thicknesses were provided. For fine tuning the spring stiffness as well as the system characteristic, the two spring widths were made available.

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B. Workpoint Considerations

The key parameters for defining the optimal system working range for a given stator configuration are the leaf spring stiffness, the working point air gap, and the actuator displacement.

Let us now have a more detailed look at the requirements for achieving an optimal working point. As mentioned before, the air gap variation to achieve the desired chiplet rotation is ±1.5 µm. An increase or decrease in the current energizing the microactuator coils causes a reduction or a growth of the actual gap length, respectively. At any time, the magnetic force created by the microactuator is the same as the spring force due to spring deflection. As a result, the air gap for the system lowered to the nominal flying height has to allow an increase or reduction, respectively, by that amount. This is only possible, if for the desired working range the leaf spring stiffness curve is steeper than the microactuator's force curve, but still allows the desired deflection of ±1.5 µm.

The considerations so far assumed a microactuator with nominal dimensions. What happens, if both spacer thickness and chip mounting height vary by ±1 µm each, i.e. 4 µm total? This means that this tolerance is added to or subtracted from the air gap. At any of these working points, the functions outlined above still have to be fulfilled.

C. Actuator Displacement

As discussed, the magnetic force of the microactuators is used to deflect the leaf springs suspending the mounting platform. Exciting both electromagnetic microactuators evenly lowers the mounting platform and thus adjusts the flying height. By opposite excitation of the actuators, the mounting platform as well as chiplet will be rotate. The displacement (the deflection of the mounting platform) depends on the spring stiffness, air gap, and on excitation current. Since it is difficult to measure the magnetic force of the system, a force – displacement diagram is difficult to establish. However, what is known accurately at any time is the excitation current. Therefore, excitation current - displacement diagrams will be used to display the working point considerations.

III. Modeling and Simulation

Finite Element Method (FEM) simulations were conducted for simulating the properties of one magnetic microactuator up to an air gap of 40 µm. For the FEM simulations, the software tool ANSYS^{TM} was used. The micro leaf springs were also designed using FEM simulations with ANSYS^{TM}. The leaf spring characteristics like the spring stiffness and the resonance frequency were simulated. For determining the properties of a real leaf spring, an evaluation of the fabricated leaf springs was required.

IV. Experimental Investigations

A. Leaf Spring Stiffness Investigation

The measurement system used for measuring the spring constants was a nanoindentation tool. The system used was the Hysitron Tribo Indenter. Typically, the nanoindenter is applied for defining the micro and nano mechanical material properties like the micro hardness [6, 7]. However, the system also lends itself to force measurements. Such a measurement was executed measuring the spring constant of the leaf spring. During the test, the leaf spring was deflected for a defined distance by applying a force using the nanoindenter tip. During the measurement process, a deflection – force curve was established. The test system allows for a maximal nanoindenter tip movement of 5 µm. Therefore, the actual spring deflection was limited to 4 µm.

To prepare the spring systems for the measurements, samples were glued onto a carrier chip in a way that the spring motion was not impeded. As center of attack of the tip, the center of the mounting platform was chosen. This way, the force exerted by both springs, left and right, was measured. When lowering the tip, both leave springs were deflected evenly. The resulting data are the spring constants for both leaf springs together. Figures 2 and 3 show the measurement results.

FIG. 2 HERE

FIG. 3 HERE

Figure 2 shows the measurement results for 5 µm thick leaf springs, while Fig. 3 shows the results for 15 µm thick leaf springs. In Fig. 2, the spring constant for a leaf spring with a 200 nm thick SiO_2 layer on the backside is also shown. The oxide layer is intending to compensate a leaf springs bending due to stresses induced during the fabrication process. Due to internal stress, the leaf springs are bent, but the deposition of a thin oxide layer compensates this effect. The hystereses shown in both figures are assumed to be measurement artifacts, apparently caused by the tip causing an imprint on the leaf spring. Table I shows a comparison between simulation and measurement results for different leaf springs constants.

TABLE I HERE

B. Air Gap Measurement

The next step was conducting magnetic measurements at various air gaps. An analysis of the microactuator's field generating capabilities was published before [8]. For measuring the air gap length as a function of the excitation current, one sample each of SLIM micromagnetic and micromechanic systems were mounted facing each other, but with no spacer in between.. The microactuator was bonded on a PCB and electrically connected. The micromechanic system was mounted on a microstage, allowing to adjusting the distance between the two pieces.

The measurements were carried out under an optical microscope. The micromagnetic system was excited, resulting in a displacement of the mounting platform. The resulting air gap was measured. These measurements were performed for various excitation currents. The deflection was determined using an LCD camera. By analyzing the pictures, the deflection was calculated using the software tool Femto Scan.

It turned out that these measurements were not very accurate, a working range could not be defined that way. However, the displacement diagrams showed the same characteristics as Laser Doppler Vibrometer (LDV) measurements, which will be reported on next.

C. *Actuator Displacement Measurement*

For a characterization of a completed SLIM system, LDV measurements were carried out using a Polytec MSV-400 Microscope Scanning Vibrometer. The vibrometer unit was mounted on a microscope. The completed SLIM device was mounted on a PCB and the actuators were excited. Using a laser spot, the deflection of a mechanical system was measured. The laser spot was centered on the mounting platform, and the displacement of this point was measured. For these measurements, a system with 5 µm thick and 100 µm wide leaf springs was used.

For an even excitation of a both microactuators, the lowering of the mounting platform was detected and for an opposite excitation, the rotation of the system was measured. The system had a spacer thickness of 80 µm. The thickness of the adhesive layers (on top and bottom of the spacer) was 30 µm. Hence, the air gap of these systems amounted to 40 µm (the actuator thickness is 60 µm and the flux closure thickness on a mounting platform 10 µm). During the measurements, the excitation current was varied and the respective displacement was measured. Figure 4 depicts the measurement results. It shows the system deflection as a function of the excitation current for a leaf spring with a thickness of 5 µm and a width of 100 µm.

FIG. 4 HERE

Not only the linear system's displacement was measured, but also the rotation. For this measurement, one half was excited with a current of 30 mA and the other one with 60 mA. In this case, the displacement of the left and the right part of the device was measured. The measurement points were on the intersection the leaf springs' centerlines and the mounting platform. The microactuator was excited, the mounting platform moved, and the deflections on both sides were measured. After that, the difference of the deflection was calculated. A difference in the deflection of 500 nm could be detected. Thus, the lateral deflection of the mounting platform was 250 nm. Because the measurement points were located about 425 µm away from the rotational axis, the rotational angle was 0.0337°. This rotational angle calculated with respect to the chiplet location (i.e. the read/write head on the chiplet) resulted in a lateral deflection of about 118 nm. The location of the read/write head on the chiplet was 200 µm away from the rotational axis. The required system rotational angle is 0.18°. The measurement shows, that this rotation can be achievable, because 20 percent of the desired rotational angle of 0.18° was reached at an air gap of 40 µm and 20 percent of available current.

V. Result

After analyzing all measurement results, the working point was determined. Fig. 5 depicts the results in the form of the system's working diagram. It shows the family of force curves for an actuator excitation between 30 mA and 200 mA. It also presents the spring constants for 5 µm thick springs with a width of 100 µm and 150 µm as measured, intersecting at various maximal air gaps. Between an air gap of 20 µm and 30 µm a leaf spring with the dimensions 5 µm x 150 µm x 500 µm can be used. In both cases, the condition to allow for a tolerance buildup of 4 µm can be fulfilled, leaving room for margin in regard of spring thickness variation. Since the wider spring is stiffer, it is more desirable since it will result in a higher resonance frequency of the system.

VI. Conclusion

The optimal operating point of the SLIM could be determined by conducting a series of experiments. For determining the actual spring constant of the leaf springs suspending the mounting block for the chiplet, a nanoindentation system could be used as a force gauge. While air gap measurements of the excited system under a microscope proofed to be too inaccurate, the actual displacement characteristics could be determined by applying LDV. By analyzing the magnetic force diagram and the micromechanics spring system characteristics, an operating range for the microactuator could be pinpointed. For optimal operation, the system's functional air gap has to be greater than 20 µm. In this area, the slope of the spring constant is greater than the one of the magnetic force curve. The measurements show that for an air gap between 20 µm and 30 µm, a leaf spring with a width of 150 µm can be used. For an air gap greater than 30 µm the smaller leaf spring with the dimensions 5 µm x 100 µm x 500 µm has to be applied. Due to its greater stiffness, the wider leaf spring is more desirable.

Acknowledgment

This work was sponsored in part by the European Commission within the Framework 6 Information Society Technologies Programme's Specific Target Research Project (STREP) PARMA - Performance Advances in Recording through Micro Actuation. The authors are indebted to the Polytec Corporation for its support in conducting LDV measurements.

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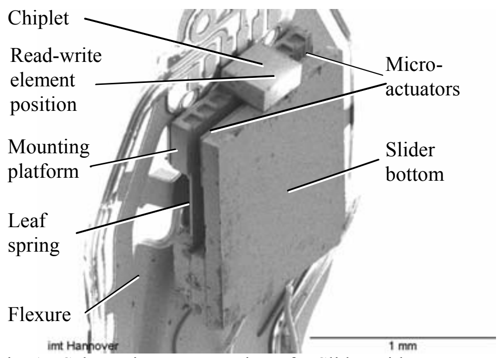

Fig. 1. Schematic representation of a Slider with an Integrated Microactuator (SLIM)

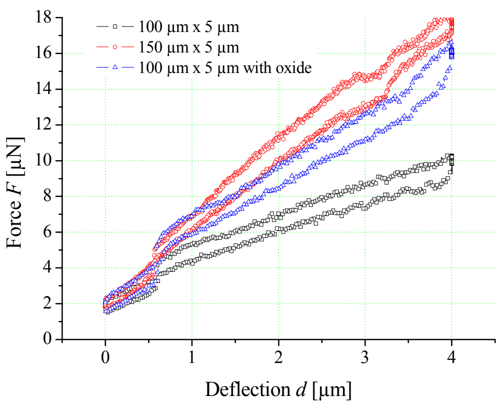

Fig. 2. Spring constant measurements using nanoindentation for 5 µm thick leaf springs

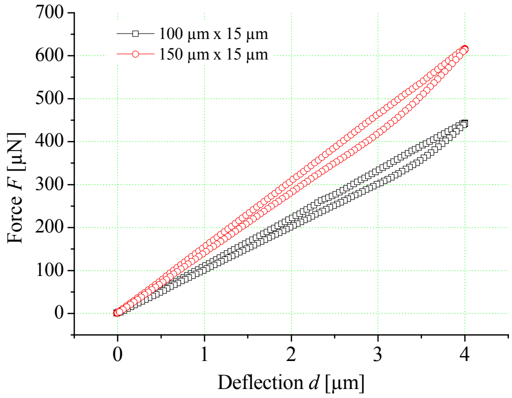

Fig. 3. Spring constant measurements using nanoindentation for 15 µm thick leaf springs

TABLE I
COMPARISON BETWEEN SIMULATION AND MEASUREMENT RESULTS

Leaf spring typ (L x W x T) [µm]	Measured spring system constant [µN / µm]	Simulated spring system constant [µN / µm]
A) 500 x 100 x 5	2.6	3.9
A_1) 500 x 100 x 5 (oxide)	4.2	-
B) 500 x 150 x 5	4.5	5.8
C) 500 x 100 x 15	112	105
D) 500 x 150 x 15	155	159

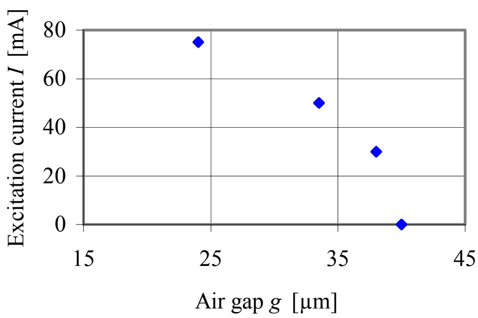

Fig. 4. LDV measurement results of the system's deflection as a function of the excitation current for a leaf spring with a thickness of 5 µm and a width of 100 µm

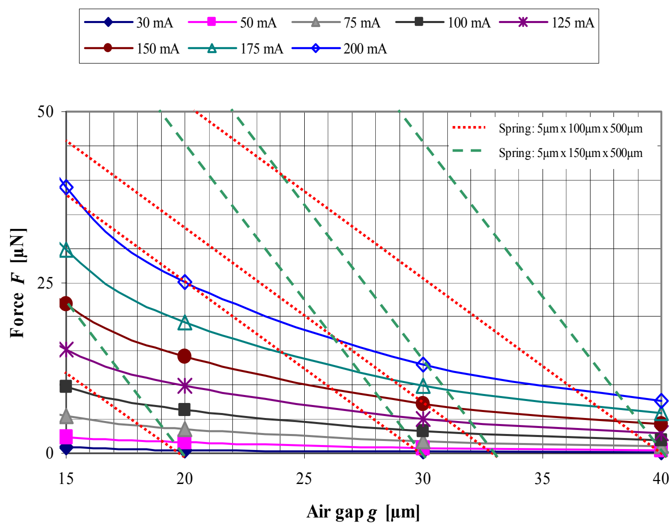

Fig. 5. System working diagram