

SEVEN-AXIS TESTER WITH SERVO-CONTROLLED FLY-HEIGHT FOR MAGNETIC RECORDING METROLOGY

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INTRODUCTION

In magnetic data storage systems, dimensions are shrinking rapidly toward the nanoscale. Magnetic recording heads have critical feature sizes below 100 nm, while they are flown in close proximity to a fine-grained recording medium at 5-15 nm fly-heights, which are controlled in a disc drive by a hydrodynamic air-bearing on a $1 \times 1 \text{ mm}^2$ slider surface. The linear density of recorded information is determined by the bit-length, which is approaching 25 nm. At these dimensions, metrology is a critical enabler for sustaining product quality and reliability. Several aspects of head performance must be quantified with precision metrology: the high-frequency performance of the write and read heads [1], the spatial extent of the magnetic field generated by the writer and the spatial field sensitivity of the read head [2-4]. None of these aspects are easily tested using conventional spin-stand recording metrology. Previous studies have shown the capability for measuring these effects at the level of individual recording heads and sliders, using scanning probe contact write/read metrology [1-4]. However, while these measurements demonstrate proof-of-principle, they are not extendable to development or production scale because of slow data gathering speeds and irreproducibility of the slider contact geometry, particularly the lack of knowledge of the head-medium or head-sensor spacing. We report here on the design and mechanical performance of a recording metrology platform with the goal of testing individual recording head sliders with a user-adjustable, servo-controlled fly height and high bandwidth electrical interconnect.

ROTARY, PITCH/ROLL, AND LINEAR STAGE ASSEMBLY

Figure 1 shows the tester. In order to deliver sufficient statistics in a minimum time, we chose to implement a rotary tester. This design uses

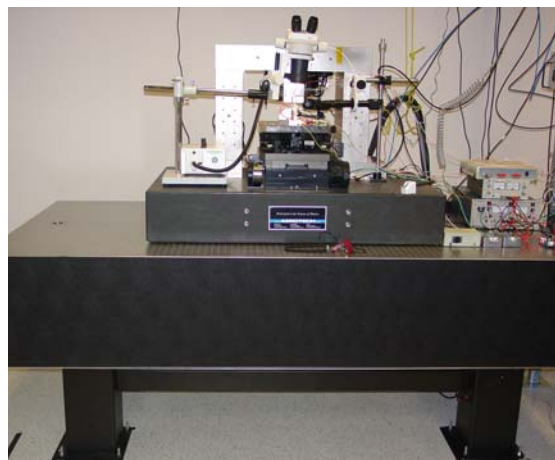


FIGURE 1. Rotary Magnetic Recording Tester



FIGURE 2. Inverted air bearing rotary stage with disc vacuum chuck

an air-bearing rotary stage which can rotate at speeds up to 400 RPM, with asynchronous error motions less than 5 nm. The rotary stage is encoded with 0.1 μRad angular resolution, enabling 2.5 nm linear resolution along the circumference at 2.54 cm radius. This stage is mounted in an inverted configuration (Figure 2), and the recording media disc is attached to the stage with vacuum. To load and unload the slider from the tester, a 4-axis positioning system is used (Figure 3 – note coordinate axes). This system includes a 300 mm linear travel air bearing stage (X-axis) with magnetic



FIGURE 3. Close-up of the linear air bearing stage and one of the pitch/roll/z adjust stages

pre-load such that when the air is removed, the carrier can be locked in position. Once locked in position, the X-axis is stable to < 2 nm p-p in a 200 Hz bandwidth. To successfully perform magnetic recording, the surface of the slider must be maintained at < 5 microradian roll (about Y-axis) and 50 microradian pitch (about X-axis) with respect to the disc surface. Three wedge z-stages are mounted on the linear stage, and are arranged at 120 degree angles to provide ~ 7 milliradian angular travel with 13 nanoradian nominal angular resolution for controlling slider pitch and roll, or 1.2 mm of z-travel (z perpendicular to the disc) with 2 nm encoded resolution.

The baseplate mounted on the tip-tilt-z stage assembly has been ground and assembled parallel to the disc vacuum chuck to an angle of 5.4 μrad in the x-direction and 0.54 μrad in the y-direction (Figures 4-5). When locked in place, the stability of this baseplate relative to the disc is 1.4 nm p-p (0.23 nm rms) in a 200 Hz bandwidth (6 second capture from an optical interferometer) in the x-direction, and 3.2 nm (0.66 nm rms) in the z-direction respectively

(Figure 6). For a 60 second capture, the p-p deviations are 7.1 and 8.9 nm for x and z respectively. The circular flatness of the vacuum chuck measured with respect to the system baseplate is 100 nm p-p at a 25 mm radius. With a 95 mm diameter glass disc mounted to the

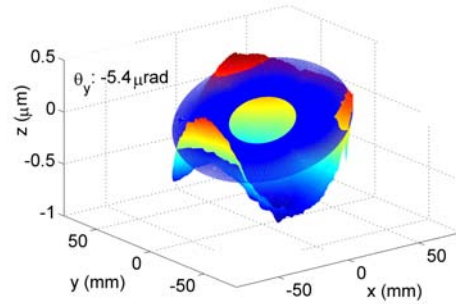


FIGURE 4. X-axis vacuum chuck parallelism relative to the tip-tilt-z platen. The angle about the y-axis is $-5.4 \mu\text{rad}$.

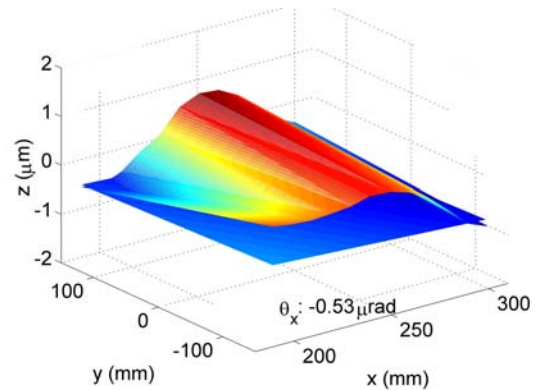


FIGURE 5. Y-axis vacuum chuck parallelism to the tip-tilt-z platen. The angle about the x-axis is $-0.52 \mu\text{rad}$.

vacuum chuck, the resulting disc circular flatness is < 800 nm p-p at a 25 mm radius, largely caused by the disc.

SLIDER MOUNTING AND PIEZO ASSEMBLY

To perform suspensionless magnetic recording at ultra-high frequencies using sliders, we require a means to hold a single slider, as well as a high-bandwidth interconnect. We also require a means to scan the slider along the radial or cross-track direction of the disc (Y-axis). Finally, the slider's distance from the disc must be controlled with nm precision. Figure 7 shows the slider clamp assembly with a 40 GHz interconnect, a 15 μm travel piezo translator, and a closed loop single-axis flexure stage (15 μm travel along the y-direction). Figure 8 displays a close-up of the slider clamp assembly

showing the clamping mechanism, the tip of an optical fiber interferometer, and a loaded slider for reference. The raised ring around the fiber tip and the pin provide reference surfaces to align the slider during loading. Finally, there is a vacuum hole directly beneath the slider, which connects to the tubing shown in the top of Figure 8, to add additional clamping force and to stabilize the slider during the loading and aligning process.

PITCH AND ROLL ADJUSTMENT

The slider roll axis is perpendicular to the linear stage. To adjust a slider roll, we employ a

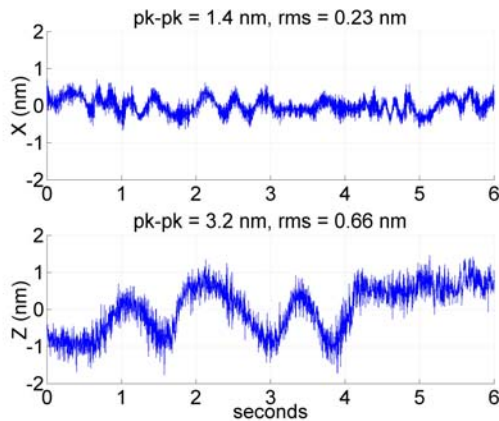


FIGURE 6. In-position stability over 6 seconds with 200 Hz bandwidth – top graph, x-axis in-position stability: p-p deviation = 1.4 nm, rms = 0.23 nm. Bottom, z-axis in-position stability: p-p = 3.2 nm, rms = 0.66 nm.

measurement station before the rotary stage, (foreground of Figure 3). This station has an optical fiber interferometer to measure the variation in slider height as the linear stage is translated. By adjusting the pitch and roll stages, a finite roll can be corrected to $< 1 \mu\text{rad}$. For a 1 mm wide slider, this angle corresponds to a height differential of 1 nm across the entire slider width. Slider pitch is controlled by scanning the z-tip-tilt stages to vary the pitch angle and measuring the change in slider-interferometer spacing. For a properly aligned interferometer with respect to the rotational axis of the pitch adjustment, a slider at zero pitch will give a symmetric response. A finite pitch angle can be introduced by offsetting this curve.

CONTROLLING SLIDER HEIGHT

The optical fiber interferometer enables us to achieve nm-scale control over the slider-to-disc separation using a digital servo control loop,

which is closed around the interferometer, in order to emulate fly heights in the 5-15 nm range. The interferometer assembly modulates the gap between the fiber tip and the surface at a constant $\lambda/2$ amplitude. The interferometer signal is fed into a DSP control board, which

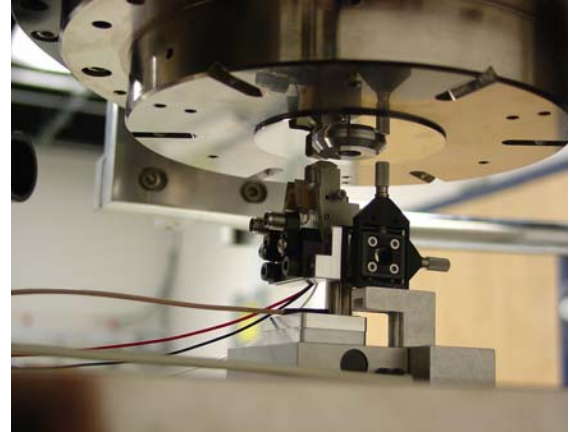


FIGURE 7. Slider clamp assembly showing 40 GHz interconnect and z-servo piezo, as mounted on the cross-track piezo stage, in proximity to the disc as mounted on the rotary stage.

performs the servo control by changing the voltage applied to the $15 \mu\text{m}$ piezo translator beneath the slider clamp assembly. Figure 9 shows the $\sim 700 \text{ nm}$ p-p circular flatness obtained when the disc is rotated and the flatness measured with the integrated optical fiber interferometer. Figure 9 shows the same signal measured with the DSP servo-control loop enabled. The maximum deviation from average over a single revolution is $\sim 5 \text{ nm}$, and on average over a rotation, the slider is within $\pm 1 \text{ nm}$ of zero deviation. This p-p deviation of

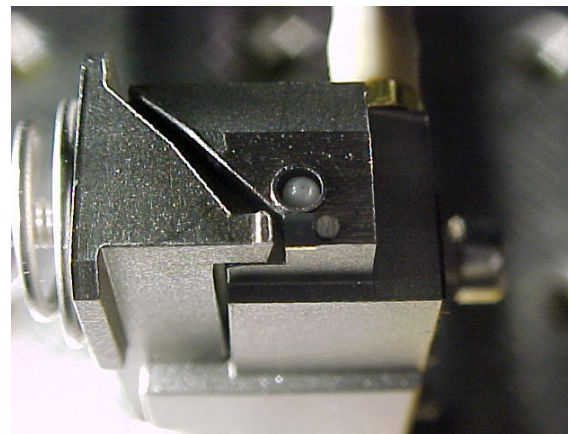


FIGURE 8. Close-up of the slider clamp showing the clamp, the slider, and the optical fiber. The slider dimensions are $\sim 1 \times 1 \text{ mm}^2$.

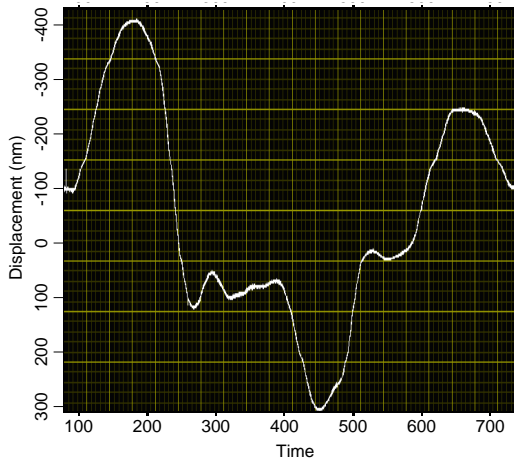


FIGURE 9. Interferometer measurement of rotating disc on vacuum chuck showing < 800 nm p-p circular flatness (rotational speed is 36 deg/sec).

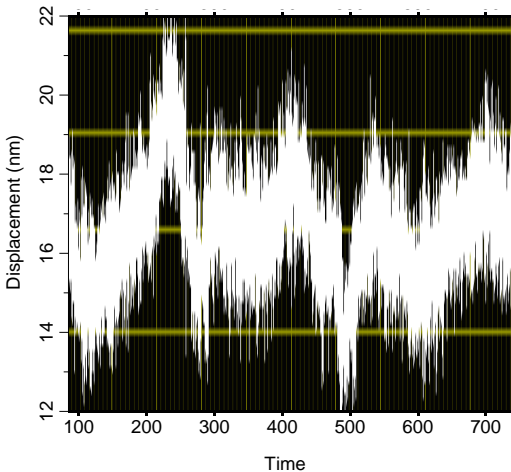


FIGURE 10. Interferometer measurement of displacement for the same disc shown in Figure 9, only with the DSP-based servo system engaged. The largest deviation from average (0-p) is ~ 5 nm, and the rms deviation is ~ 2 nm

10 nm represents a 100x reduction of the disc flatness.

CONCLUSION

A number of noise sources could potentially contribute to the observed deviation with the servo control loop enabled. For example, there is a noise peak at 1.5 kHz with higher harmonics. We suspect this noise originates in the interferometer laser or piezo power supply, as this noise was not correlated with the rotation of the disc. However, mechanical sources

cannot be ruled out, such as coupling between the various z-stages, or acoustic coupling from background laboratory noise. If the data in Figure 10 is filtered at 1 kHz with a Butterworth filter, a p-p z-error signal below 1 nm can be achieved, suggesting that with additional noise reduction, for example, quieter power supplies and potential acoustic shielding, this instrument design can deliver variable fly height magnetic recording at the 5 nm level for testing and development of advanced recording components.

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