A Dynamic Scratch Test to Study Read/Write Head Degradation due to Head-Disk Interactions

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A dynamic scratch test is described to study read/write head degradation due to head-disk interactions. The test involves flying magnetic recording heads over custom-made asperities on the surface of a hard disk. Degradation of the read sensor amplitude, asymmetry, magnetic stability, pinned-layer flip, overwrite and resistance were observed. The changes are attributed to stress induced magnetic anisotropy and/or scratching/smearing damage. Testing comparison of a giant magnetoresistive (GMR) and a tunneling magnetoresistive (TMR) head design showed that the TMR design was more susceptible to abrupt resistance decrease and amplitude loss, consistent with scratching/smearing damage at the air bearing surface.

***Index Terms*—Asperity, hard disk drive, head degradation, head-disk interaction, scratch testing, tribology.**

I. Introduction

As THE head-disk spacing is reduced to increase areal density in hard disk drives, the likelihood of head-disk interactions increases. If the head-disk interactions involve contact to the slider body, then issues related to flyability, wear and debris pickup are of concern. However, when the head-disk interactions involve direct contact between a sharp disk asperity and the read or write transducers, then much more serious and immediate read/write head degradation can result. We use the term “head degradation” to describe any adverse change to the magnetic performance or stability of the read/write transducers.

Head degradation can result from a variety of mechanical overstress mechanisms. It can be due to mechanical deformation of the read sensor, e.g. scratches through the carbon overcoat that cause smearing or shorting between head structures. Or it can be due to changes in mechanical stress near or at the surface of the read/write transducers, leading to magnetic changes via stress induced magnetic anisotropy. While such a severe level of damage to the read/write sensor is hopefully rare during disk drive operation, it can happen and is a reliability concern. Therefore, it is both interesting and important to study and understand the behavior of the read/write transducers while flying over different types of disk asperities.

The goal of this work is to describe a “Dynamic Scratch Test” that can be used to study and quantify read/write head degradation due to head-disk interactions, and use it to compare the robustness of GMR and TMR head designs to head degradation.

II. Experimental

The dynamic scratch test has three unique features: 1) the ability to make reasonably reproducible, customized asperities on the surface of a disk, 2) the use of a specially modified Guzik XY spin stand with an *in--situ* quasi-static (QST) transfer curve measurement capability, and 3) a custom test algorithm to repeatedly sweep the read/write transducers over the disk asperity.

A. *Making the asperities*

Real disk asperities can result from processing, handling, or load/unload “dings”. For this head degradation testing, the challenge is to repeatably and consistently make individual micron-sized, artificial defects on the disk that a flying head can interact with but not result in a head crash. The artificial defects used in this study, shown in Fig. 1, were scratches or indentations on the disk, or hard particles embedded in the disk. Customized, artificial asperities were made using a CSM Instruments Nano-scratch tester. The disk was placed on the CSM open platform Nano-scratch tester, which has an optical microscope (50X to 1000X), an atomic force microscope (AFM), and separate mechanisms to produce scratches and

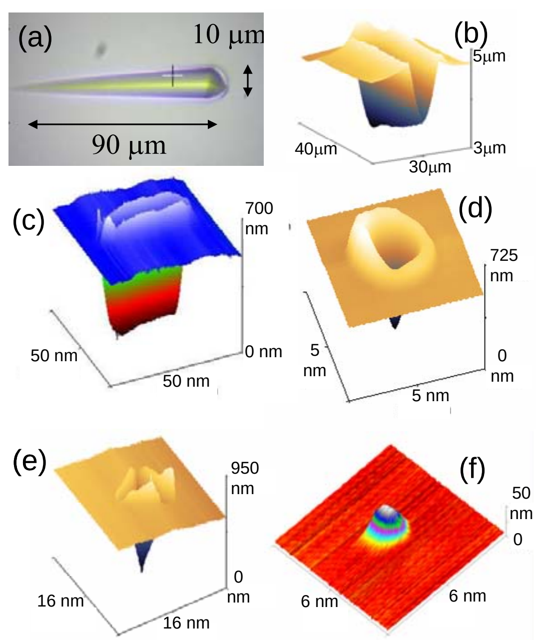

Fig. 1. (a) Optical and (b) atomic force microscope (AFM) scans of a progressive load scratch, (c) a constant load scratch, (d) an indentation using a 10 µm Rockwell conical tip (e) an indentation using a Berkovich tip, and (f) an embedded TiC particle.

indentations. Disk indentations and scratches were then made on the smooth disk surface using either a Rockwell spherical conical or sharp Berkovich diamond-tipped stylus. The radius of the conical tip ranged from 1µm to 50 µm. Figure 1 shows optical and atomic force microscope (AFM) scans of (a,b) a progressive load scratch, (c) a constant load scratch, (d) an indentation using a 10µm Rockwell conical tip, (e) an indentation using a Berkovich tip, and (f) an embedded TiC particle.

The pile-up of the disk material at the edge of the scratch or indentation is the asperity that interacts with the surface of the read/write transducers during the dynamic scratch testing. Testing showed that scratches made in the circumferential direction resulted in more carbon overcoat wear and head degradation much more easily than radial scratches. The starting pile-up was chosen to result in head degradation in less than 10 minutes of sweeping. For an indentation or scratch made with a conical tip with radius 10 µm (1µm), the starting pile-up height was in the range of 100nm (400nm).

When a harder material than the disk pile-up was desired, the Nano-scratch tester was used to embed diamond or TiC particles into the disk. Individual particles were pushed into the disk using a flat, 10µm x 10µm diamond "punch" tip. Figure 1(f) shows an AFM image of an embedded TiC particle with a diameter of 600 nm, but with only 40 nm protruding above the disk surface.

The pile-up height is determined by the normal force, F_N, tip radius and shape, and the Young's modulus and work hardening properties of the disk material and substrate [1]. Figure 2 shows an example of the maximum pile-up height vs. F_N around an indentation using a Rockwell conical diamond stylus with a tip radius of 1 µm. For a given tip and disk, the pile-up was easily controlled through the normal force.

Using these techniques, a large variety of asperities with varying length, width, height and hardness were made possible by choosing the diamond tip shape, normal load force, profile and media substrate, or embedded particle type and size.

B. *Spin stand with in-situ quasistatic test*

Quasistatic transfer curves are a measure of the read sensor's intrinsic signal vs. external magnetic field. The peak-to-peak amplitude measured from the transfer curve is

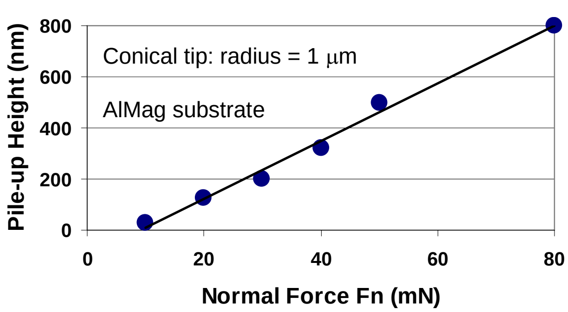

Fig. 2. P-le-up height vs. normal force, or load, around an indentation using a Rockwell conical diamond stylus with a tip radius of 1 µm.

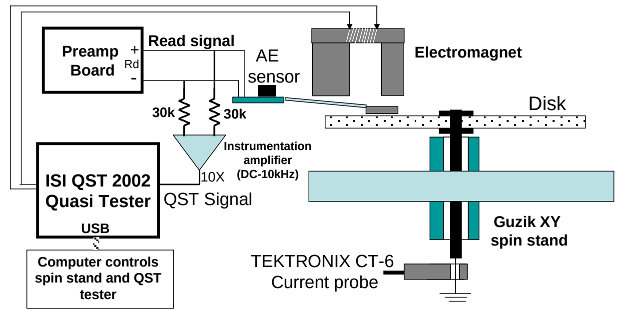

Fig. 3. Experimental setup showing the modified spin stand with *in-situ* quasi-static test capability.

independent of the writing process or spacing when flying on the disk, and is invaluable for detecting changes in intrinsic sensor amplitude, Barkhausen noise, magnetic instability, and slope. Figure 3 shows a schematic representation of a Guzik XY spin stand combined with an Integral Solutions International 2002 QST tester that enables *in-situ* quasistatic transfer curve measurements while the head is flying on the disk with radius 3.5 inches and at 5400 to 15,000 RPM. The DC-coupled signal for the QST tester was derived from an instrumentation amplifier connected to signal traces from the read head. The spin stand and ISI QST tester are controlled from the same computer using a custom WITE module that executes the dynamic scratch test algorithm.

C. *Dynamic scratch test algorithm*

After loading the head onto the spinning disk, the custom asperity was precisely located using an acoustic emission sensor and the thermal asperity (TA) signal from the read-back sensor itself. The read/write transducers, with a fly height of about 8 nm, were then swept repeatedly over the asperity with a range of +/- 10µm. Each sweep lasted 30 seconds. This focused the interaction and wear damage to the read/write transducers. After each sweep across the asperity, the slider was moved off of the asperity and the dynamic electrical test (DET) magnetic head parameters and quasistatic transfer curve were measured. The total test time was typically 10 minutes.

III. RESULTS

A. *Read head degradation*

Figure 4 shows the quasistatic transfer curves for a GMR

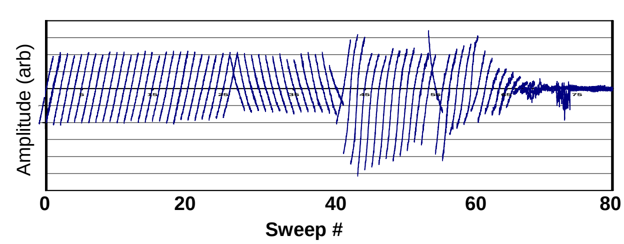

Fig. 4. Quasistatic transfer curves vs. sweep number for a GMR head swept across a progressive load scratch on the disk.

read sensor after each 30 second sweep across a circumferential progressive load scratch shown in Fig. 1(a). Note the abrupt slope reversal, or "pin flip" after the 28th sweep across the defect, the flip back after the 43rd sweep, and other dramatic changes in amplitude and asymmetry. The GMR sensor resistance change started at sweep #60, so the pin flips occurred prior to any resistance change.

The slope reversal is explained by reversal of the pinned layer direction in the GMR stack and is similar to that caused by a current transient from an electrostatic discharge (ESD) [2]. However, in this case, the pin flip is attributed to mechanical overstress, since the current probe shown in Fig. 3 measured no current transient from the disk to ground.

Other changes in the QST transfer curve were also observed, e.g. the appearance of Barkhausen noise and hysteresis.

Figure 5 shows plots of the changes in GMR (top) and TMR (bottom) resistance and DET track averaged amplitude (TAA) vs. time during dynamic scratch testing. For the typical GMR head, the TAA would decrease, followed eventually by a gradual resistance increase that was consistent with sensor lapping. In contrast, the TMR head shows an abrupt resistance and TAA decrease. For the same type circumferential

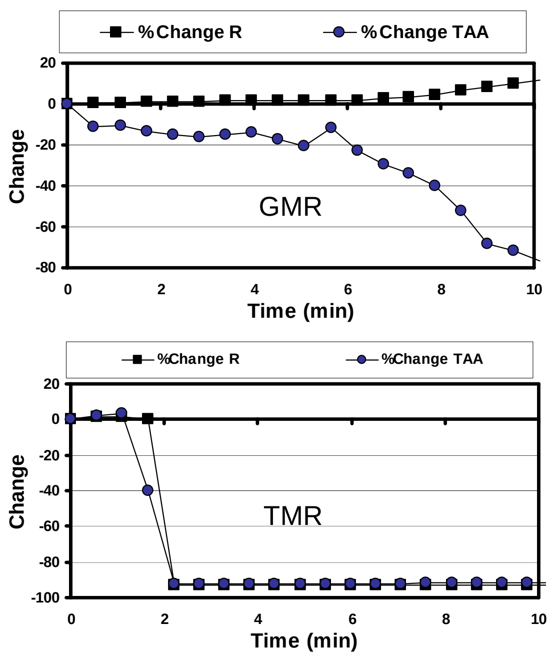

Fig. 5. Changes in GMR (top) and TMR (bottom) resistance and track averaged amplitude (TAA) vs. time during dynamic scratch testing.

progressive load scratch shown in Fig. 1(top), only the TMR heads sometimes showed this abrupt decrease in resistance.

Failure analysis of the TMR heads that decreased resistance during dynamic scratch testing showed carbon overcoat (COC) wear as wells as smearing/scratching of the TMR sensor. Figure 6 (top) shows an Auger electron image of the read/write transducers, with brighter regions indicating wear of the carbon overcoat. This confirms head disk interactions over and directly to the read/write transducers.

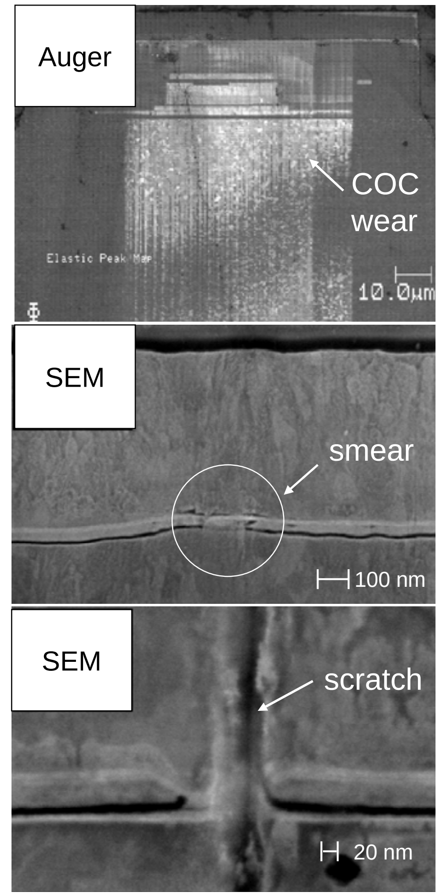

Fig. 6. (top) Failure analysis of three different TMR heads that abruptly decreased resistance during dynamic scratch testing. Top: Auger images with brighter regions that indicate wear of the carbon overcoat, confirming head disk interactions over and directly to the read/write transducers. Middle: SEM image showing smearing between the lead and shields. Bottom: Scratch through TMR sensor.

Figure 6 (middle) shows an SEM image showing smearing between the lead and shields. Figure 6 (bottom) shows a scratch directly through the TMR sensor. So the abrupt resistance decrease during the dynamic scratch testing of the TMR heads is explained by scratching/smearing of the sensor or leads, combined with COC wear.

Using a harder, embedded particle instead of the softer pile-up around a scratch or indentation would also be expected to yield severe head degradation. Figure 7 shows the resistance behavior of a TMR sensor while flying over the hard, embedded TiC particle shown in Fig. 1(f). Note the abrupt resistance decrease after the 3rd sweep, which is consistent

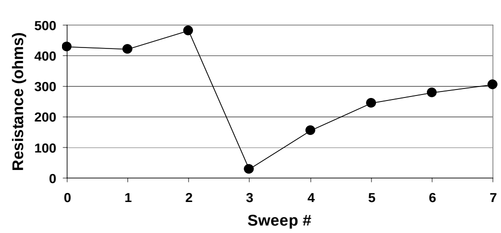

Fig. 7. Resistance of the TMR sensor vs. sweep across embedded TiC particle.

with smearing/shorting of the tunneling barrier at the air bearing surface. The partial resistance recovery after additional sweeps is explained by further “lapping” away of the initial scratch or smear.

No pinned layer flipping was observed in these TMR head samples. However, they were more easily degraded by head disk interactions that cut through the carbon overcoat on the head. In contrast, the GMR design exhibited pin flip but did not show the abrupt resistance decrease.

B. Write Head Degradation

Figure 8 shows the TMR sensor resistance, TAA and overwrite after each sweep across an indentation on the disk. Just prior to the resistance increase, which indicates that the COC on the head has worn off and the sensor “lapping” has begun, the TAA and overwrite decrease dramatically. The amplitude of the TMR sensor measured by the QST transfer curve did not change until after the 80th sweep. This behavior is consistent with damage to the writer that affects its ability to write transitions on the disk. Auger images showed that this write head degradation occurred prior to any significant COC wear over the writer.

C. Disk Defect Wear

The asperity itself wears as it interacts with the surface of the head, especially when it consists of the piled-up disk material around a scratch or indentation. Examples of dramatic burnishing of the disk asperity are shown in Fig. 9, which shows AFM scans of an indentation before (a) and after (b and c) dynamic scratch testing. The height before (after) scratch testing was 600 nm (25nm), so severe burnishing of the defect occurred during the test. Figure 9(c) shows an AFM of another indentation after dynamic scratch testing, showing a trail of debris.

IV. Discussion

The *pressure* (force/area of contact) exerted by the asperity pile-up on the surface of the read/write head plays a critical role in head degradation. Since the contact area is a function of the radius of curvature (R_c) of the pile-up, the initial R_c of the pile-up or embedded particle directly affects head degradation, the wear rate of the COC on the head, and the burnishing rate of the asperity. Experiments revealed that pile-up with an $R_c < 0.1\mu m$ or $R_c > 20\mu m$ did NOT result in head degradation. For $R_c < 0.1\mu m$, the narrow pile-up burnished away before damaging the read/write sensors. For $R_c > 20\mu m$, the head flew over the blunt pile-up for hours without showing any sign of COC wear or head degradation.

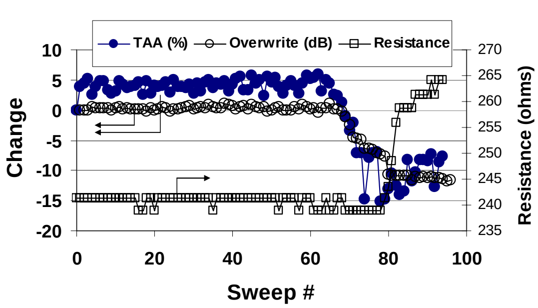

Fig. 8. Resistance, TAA and overwrite vs. sweep across indentation on AlMag disk.

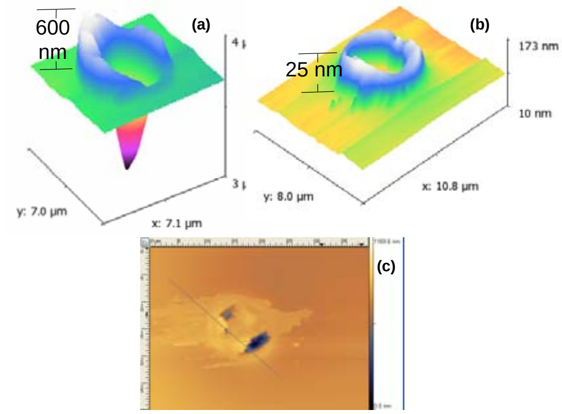

Fig. 9. AFM scans of an indentation before (at) and after (b) dynamic scratch testing. The height before (after) scratch testing was 600 nm (25nm). (c) AFM of another indentation after dynamic scratch testing, showing a trail of pile-up debris. Indentations were made using a Rockwell diamond tip with a 1µm tip radius, and a normal load of 500 mN.

V. Conclusion

Using the Nano-scratch tester enables the fabrication of custom asperities of many different shapes, size and hardness, and makes detailed studies of head degradation due to head-disk interactions feasible for the first time.

Changes in read sensor resistance, amplitude, Barkhausen noise and “pin flip”, as well as writer degradation, were observed during the dynamic scratch testing. TMR sensors were found to be less robust than GMR heads to scratching/smearing damage.

It is concluded that dynamic scratch testing provides valuable information about the strengths and weaknesses of the read/write transducers during head disk interactions, and for studying the wear characteristics of asperities on the disk, the COC on the head, and the materials in the read/write head structures.

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