Scratch Testing of Hard Drive Components
(Hard Disks and Sliders)

Application Note

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Introduction

A common failure of a hard drive occurs when a computer is moved or dropped and the read heads come into contact with the hard disk platters. If permanent deformation is caused from this contact you may get the infamous blue screen. To protect the disks and sliders, a diamond-like-carbon (DLC) coating is applied to each component. The coatings on the hard disks are usually 4 nm to 30 nm of thickness and the coatings on the sliders are typically 2 nm to 4 nm of thickness. Manufacturing conditions greatly affect the mechanical properties and the durability of the DLC coatings. Typically, instrumented indentation testing (nanoindentation) is used to determine the mechanical properties of thin films; however, due to overwhelming substrate influence,

nanoindentation will not provide substrate independent mechanical properties of the ultra-thin DLC films.

In the situation where substrate influences overwhelm quantitative results of indentation, a nanoindenter can be used to perform scratch testing to obtain qualitative results through mimicking product failure in a controlled test. For testing hard disk and sliders, a scratch test can be used to evaluate the DLC film failure. In this application note, the results from scratch testing—using the Agilent G200 Nano Indenter® and the stage of the Nano Vision® option —four hard disk samples and a slider from a hard drive are compared showing clear and statistical differences in the response of the different coatings on the hard disks and positional variation of the coating on the slider.

Samples

The Hard Disks:
Four new hard disk platters, each processed using different parameters, were provided by a manufacturer and were described as having the axisymetric cross-sectional geometry shown in Figure 1. These platters did not have lubricants applied to the surfaces.

The Slider:
A slider and read head assembly was removed from a used, but still working, hard drive that was produced in June 2000. A microscope view of the slider is shown in Figure 2.
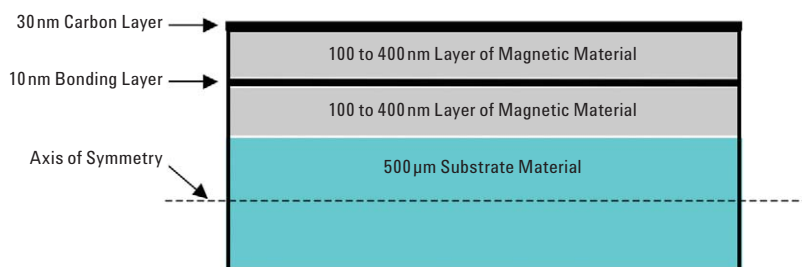

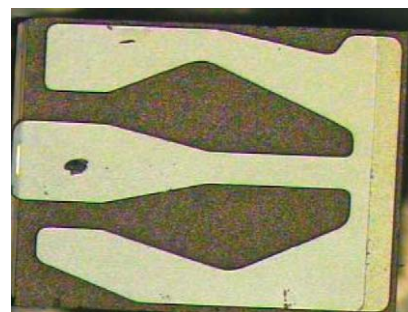Figure 1. Cross-sectional diagram of the hard disk samples showing the 30 nm coating of DLC.

30 nm Carbon Layer
10 nm Bonding Layer
100 to 400 nm Layer of Magnetic Material
100 to 400 nm Layer of Magnetic Material
Axis of Symmetry
500 µm Substrate Material

Figure 2. The slider removed from the gimbal device of a hard drive. Sliders typically have a 2 nm to 4 nm coating.

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Step 1: Original Surface Scan

Step 2: Ramp Load Scratch Segment

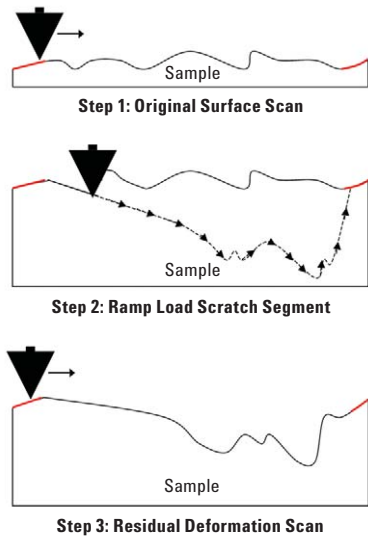**Step 3: Residual Deformation Scan**

Figure 3. Diagram of the three-step ramp load scratch test. Red lines show the areas of pre and post profile scans used to perform leveling of the 3 steps.
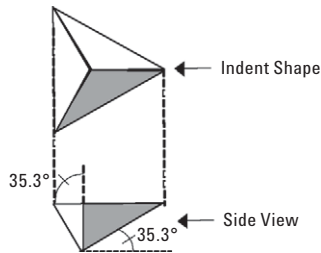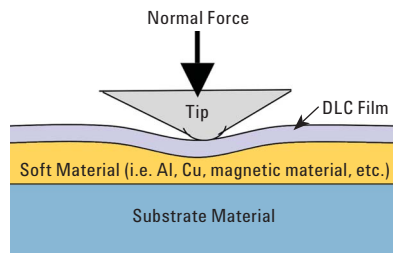

Figure 4. Diagram of a cube corner tip.

Figure 5. Diagram of the deformation that occurs during testing of a DLC film on soft material. Notice that the film material elastically deforms while the underlying soft material accommodates the bulk of the deformation.

Test Methodology

To mimic the contact of a head crash, a ramp load scratch test was chosen to test all of the hard disk platters and slider. In a scratch test, a tip is brought into contact with the sample; then, the tip is loaded at a constant loading rate while simultaneously translating the sample. Prior to and following the scratch test, a single-line-scan of the surface morphology is completed for comparing the original surface to the deformation caused by the scratch test. Therefore, each scratch test consists of three steps: a single-line pre-scan of the area to be scratched, the ramp load scratch test, and a final scan to evaluate the residual deformation. Before and after each step, a pre-scan and a post-scan, usually equal to 10% of the scratch length, is performed so that the software can automatically align the data in the three steps. The original and residual single-line scans allow for the evaluation of deformation mechanisms and the quantification of deformation. The scratch process is diagrammed in Figure 3.

When performing scratch testing on any sample set, it is critical that all test parameters and tip geometries remain consistent throughout the samples being compared. This ensures that qualitative comparisons can be made using the resulting data. The test parameters used in testing the hard disk samples and the slider positions are listed in Table 1 and Table 2, respectively.

The tip chosen for conducting the scratch tests was a cube corner tip with a tip radius that was less then 20 nm. A cube corner tip creates a triangular projected contact with the sample; this tip geometry creates high levels of stress in the material during the scratch. Scratches can be performed either face

forward or edge forward when using a pyramid shaped indenter. Scratching face forward with the cube corner tip acts like a snow plow and pushes the material out of the way, while edge forward cuts the material like a knife. A diagram of a cube corner tip is shown in Figure 4.

While Figure 3 depicts the tip moving across the sample, in application, the tip is held stationary while the sample is translated underneath the tip. A nanopositioning stage was chosen for translating the sample during these scratch tests. Usually, the standard motion table on the Nano Indenter G200 is used for completing scratch tests. However, a high precision positioning stage with a superior flatness of travel was required due to the dimensions of the films being tested. The nanopositioning stage chosen for this application was the same stage that is used for the Nano Vision option on the Nano Indenter G200; this stage has a flatness of travel of 2 nm over a 100 µm range of lateral travel.

Results and Discussion
Hard Disk Platters
Samples with DLC films usually exhibit excessive sink in during testing. Frequently, the film will deflect far greater than its thickness prior to failure. This is usually due to the compliance of the underlying materials that the film is designed to protect. These underlying materials are often much softer than the film allowing deformation of the underlying materials prior to film deformation or failure. Hard drive components, such as the platters and sliders, usually fall into this category of materials. Figure 5 shows a diagram of the sink-in that occurs during testing of the DLC films on top of softer underlying materials.

Scratch Length	80 µm
Scratch Velocity	8 µm/s
Maximum Scratch Load	0.8 mN
Scratch Direction	Face Forward

Table 1. Testing Parameters for the Hard Disk Samples.

Scratch Length	80 µm
Scratch Velocity	8 µm/s
Maximum Scratch Load	2.0 mN
Scratch Direction	Face Forward

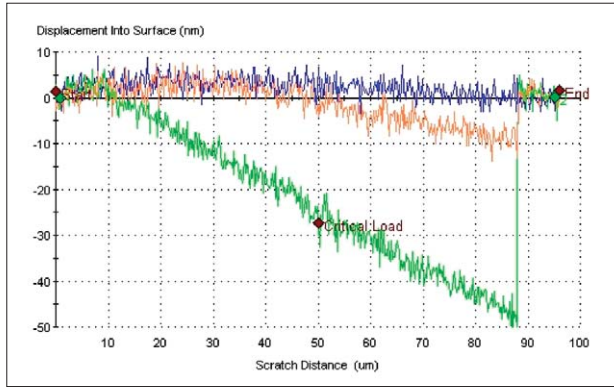Table 2. Testing Parameters for the Slider Positions.

Figure 6. Typical displacement curves for the scratch test performed on hard disk Sample 1.
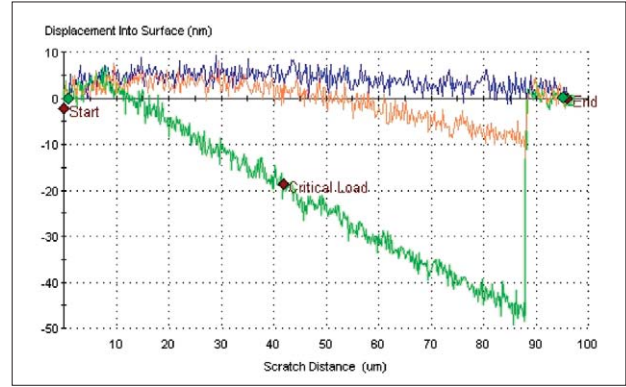

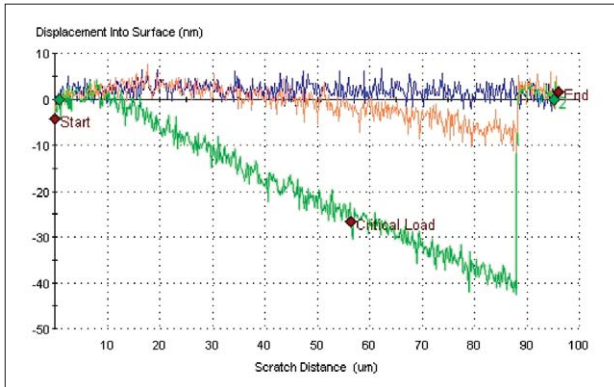Figure 7. Typical displacement curves for the scratch test performed on hard disk Sample 2.

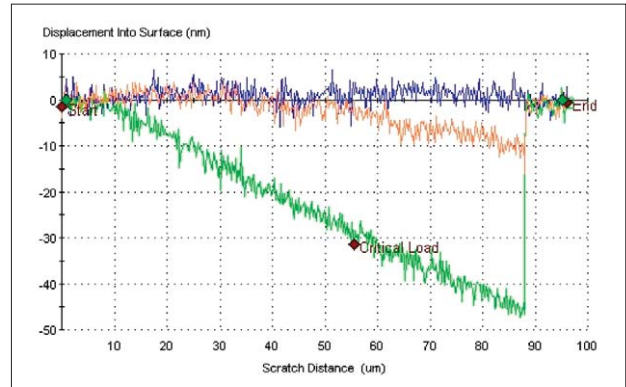Figure 8. Typical displacement curves for the scratch test performed on hard disk Sample 3.

Figure 9. Typical displacement curves for the scratch test performed on hard disk Sample 4.

Typical displacement curves for the scratch tests on each hard disk platter are shown in figures 6 through 9. Each figure contains the original surface scan (blue trace), the ramp load scratch (green trace), and the residual deformation (orange trace). Each figure has the position of critical load (point of permanent failure) marked. The critical load was chosen based on excursions in the scratch displacement curves (signifying fracture) and the amount of residual deformation. It is apparent from the displacement curves that the carbon films fractured at approximately 30 nm of penetration, with the exception of Sample 2 which fractured at a displacement that was less then 20 nm of penetration. With close examination of the curves, it is also apparent that Sample 3 (Figure 8) showed significantly less residual deformation then the other hard disk samples subjected to the same scratch loads and also showed less deformation during the scratch test
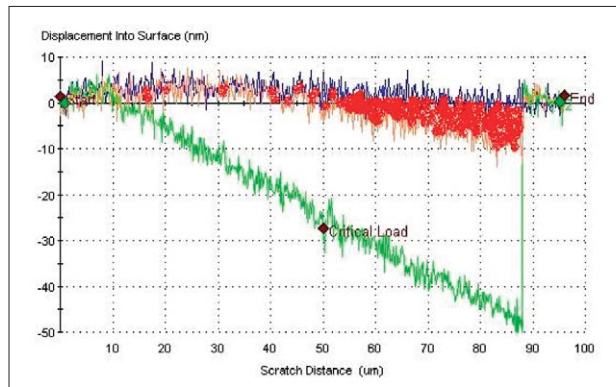

Figure 10. The Residual Deformation was calculated by determining the area between the original surface scan and the residual deformation scan. The area of deformation is shown in red.

with a maximum penetration of only approximately 40 nm – all of the other samples had a maximum penetration of over 45 nm.

Due to the differences examined in the progression of the scratch tests on each platter and the desire to quantify the amount of deformation

that occurred during the scratch test, the residual scratch deformation was defined as the area of material that was permanently deformed from the scratch test. This was calculated as the area of deformation between the original surface scan and the residual deformation scan. Figure 10 shows the area of residual deformation colored in

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red. In practice, the Agilent NanoSuite 5.0 software has a built-in function for calculating the areas under curves; this function was used in the calculation of these areas.

Table 3 lists the results of the scratch tests on the hard disk samples while Figure 11 graphically displays the Critical Load and the Residual Scratch Deformation for the samples. Notice that Sample 2 has a combination of undesirable results; this sample has both a low critical load and high residual scratch deformation. In application, Hard Disk 2 will scratch easier and have higher permanent damage than the other disks. Sample 3 and Sample 4 were the best performers because they possessed a higher resistance to permanent deformation, even though these samples had critical loads that were comparable to Sample 1. The differentiator between samples 3 and 4 was the penetration depth during the scratch segment of the test. Sample 3 exhibited a maximum penetration of approximately 42 nm, while Sample 4 exhibited maximum penetration of approximately 47 nm. A larger volume of material was affected by the scratch tests performed on Sample 4, leaving Sample 3 as the sample with the most desirable scratch resistant properties.

Sample Number	Critical Load	Penetration at Critical Load	Residual Scratch Deformation
	μN	nm	μm^2
1	471.3 ± 9.5 (1σ)	26.3 ± 0.6 (1σ)	0.318 ± 0.030 (1σ)
2	343.7 ± 36.6	18.7 ± 2.5	0.414 ± 0.044
3	478.0 ± 9.5	28.0 ± 1.0	0.246 ± 0.029
4	483.0 ± 5.2	28.0 ± 2.6	0.265 ± 0.057

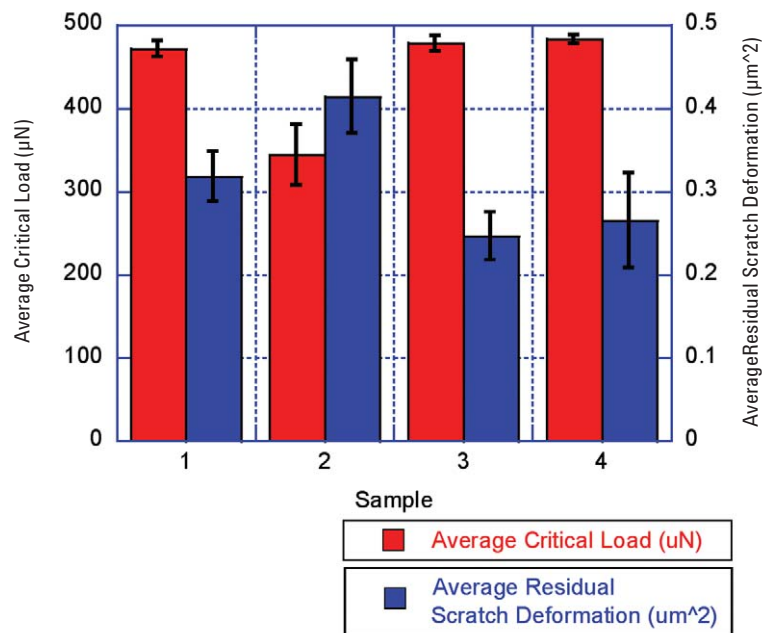Table 3. Scratch test results for the hard disk samples.

Figure 11. Scratch test results for the hard disk samples. The error bars represent one standard deviation.

Slider Positions
The slider was tested in 4 positions to determine positional variation of the carbon coating; the scratch positions are shown in Figure 12. Each position was tested three times and figures 13 through 16 display typical scratch results from each position. The results show definite positional variation in the scratch resistant properties of the slider. Figure 17 graphically displays the results of the scratch tests at each position.

All of the positions on the slider exhibited failure of the coating or underlying material. The critical loads were determined using the scratch curve and the original surface scan as a guide. For these types of coatings, it is critical that all three parts of the
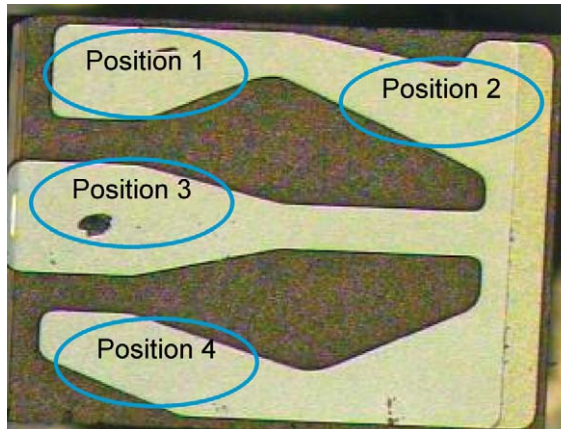

Figure 12. Slider test positions for determining positional variation.
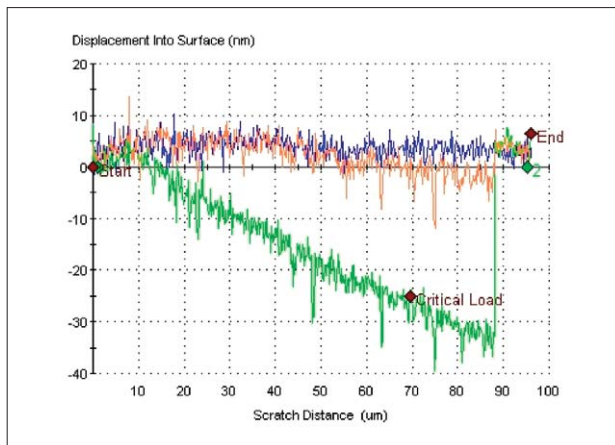

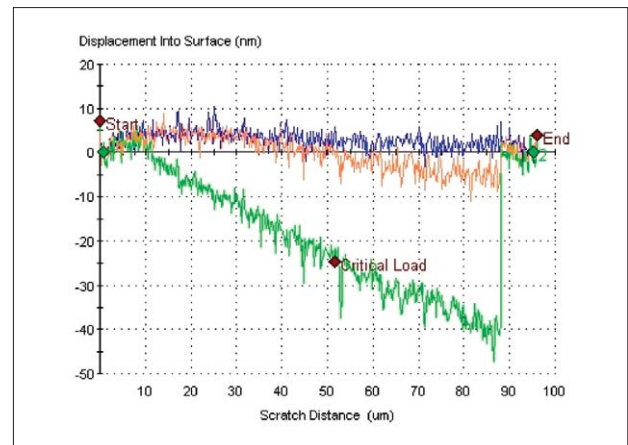Figure 13. Typical scratch result from Position 1 on the upper slider arm.

Figure 14. Typical scratch result from Position 2 on the slider shoulder.
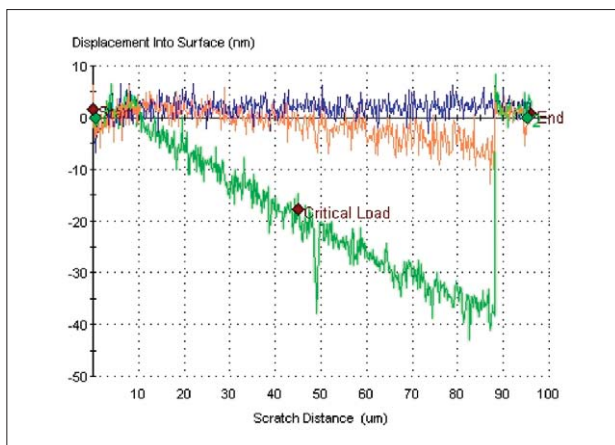

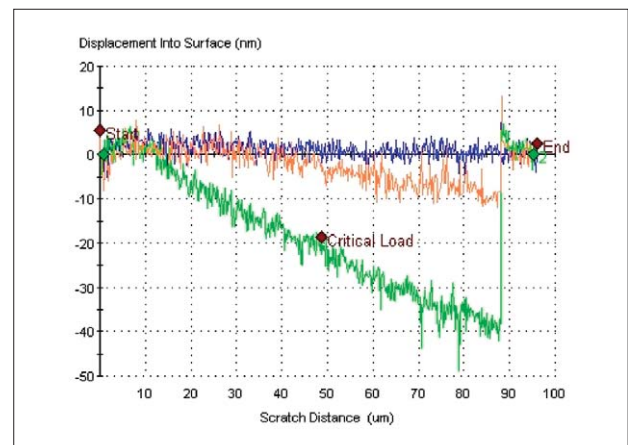Figure 15. Typical scratch result from Position 3 on the middle slider arm.

Figure 16. Typical scratch result from Position 4 on the lower slider arm.

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scratch test be displayed for analyzing the point of critical load for the test. It is easy to confuse the shearing of surface asperities with fracture of the film; therefore, the original surface scan and the residual deformation scan provide a measure of failure and fracture. Commonly, surface roughness or surface asperities will cause a large drop in displacement or a spike in lateral force; the critical load should not be chosen when a surface asperity is sheared, due to external influences in the results. The critical loads were chosen for each of these positions by locating the position where continued failure occurred. The critical load could have been chosen at the location where first chipping or fracture appears, but this also causes a larger variation in the results on DLC films and it was decided to define the critical load as the point of obvious continued failure of the sample.

Position 1 showed the best scratch response by having the highest critical load and the least amount of deformation during the scratch test. This means that, during an impact, Position 1 will have the most protection from permanent damage. Position 4 exhibited the most undesirable response by having the lowest resistance to failure and the highest amount of deformation in the material during the scratch test.

Conclusions

The Nano Indenter G200 and nanopositioning stage, supplied with the Nano Vision option, was used to measure the scratch response of thin DLC films. The results on the hard disk platters showed clear statistical differences in the scratch responses that were due to the different processing parameters. Results from the scratch tests on the slider also showed clear statistical differences

in the scratch responses that were attributed to positional variation of the film properties across the slider.

These results show the critical need for having pre-scans and post-scans of the sample's surface for nanotribology applications. In this application, the surface scans allowed the quantification of damage to be assessed. Without these scans, very few or incorrect conclusions could have been draw for these data sets.
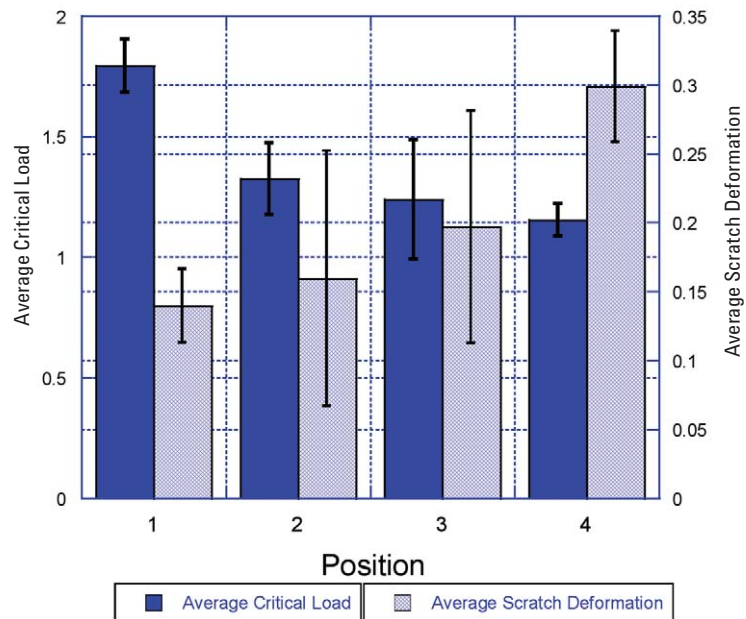

Figure 17. Scratch test results for the four slider positions. The error bars represent one standard deviation.

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