ABSTRACT
Characterization of slider motion induced by contact is becoming a critical aspect of developing advanced head-disk interfaces. While vertical motion induced by contact has been studied, very little is known about down-track motion. We have introduced a new technique where the down-track motion is captured and the dynamics in three dimensions are analyzed. We have applied this technique to measure the position of a slider as it transitions from flying to making full contact with the media surface. We find that slider motion varies considerably with varying levels of interference and that motion in all three directions is considerable. Spectral decomposition is used to identify the vibration modes that are excited in each direction, and we find that for most of the test velocities, vertical modes give rise to motion in the two orthogonal directions. In addition, we present a depiction of the vertical, down-track, and off-track position changes by plotting the position of the slider in real space coordinates to help visualize more completely the slider trajectory. Analysis of motion identifies that at some levels of interference, a majority of motion is repeatable, but that non-repeatable components increase with the amount of interference. Additionally, down-track motion is the only component whose magnitude increases monotonically with increasing interference.

INTRODUCTION
One very important aspect of head-disk dynamics is missing from both modeling and experimental study. When sliders make contact, friction is predominantly in the down-track direction, but resultant down-track motion has not been investigated. Down-track motion is usually neglected because of one of the following reasons: 1) vertical motion (changes in the fly height) is of primary concern for recording performance because it exponentially changes the field strength, 2) the suspension is considered to be infinitely stiff in the down-track direction, or 3) adding another degree of freedom may complicate the models considerably, making them intractable. However, down-track motion must exist when down-track friction forces act upon a slider. Up to this point, the magnitude of motion in this direction has not been known. If the stiffness of the loadbeam, flexure, and slider system is much larger in the down-track direction than in the vertical direction, it may not be significant. Suspension flexures are typically compliant to pitch and roll torques and have some compliance in the down-track direction. One goal of this research is assess how much down-track motion occurs when head-disk contact occurs.

EXPERIMENTAL PROCEDURE AND RESULTS
Testing was performed on a Guzik 1701A spinstand that had been modified to incorporate acoustic emission detection and to accommodate optical stages for laser Doppler vibrometry (LDV). Three separate Polytec PI LDV systems were used to interrogate slider motion and were arranged in three orthogonal directions. Each utilized a fiber sensor that focused the laser beam to a spot size of approximately 15 μm. We characterized the motion of a single slider as it made contact with media at several linear velocities. The rotational rate started at 26.6 m/s (10,000 rpm and 1.0” radius) and was decreased in 2.66 m/s increments to induce contact with varying interference to identify variations in slider motion. At each test velocity, the velocity signal was recorded before lowering to the next rpm.

In order to visualize how the slider moves while in contact, we have taken the three position signals for each linear velocity and have plotted them against each other. These phase plots provide a two-dimensional visualization of the slider position in real space during a certain segment of time. In Fig. 1, we show the phase plot of the vertical motion versus the down-track motion from one of the test conditions: 21.3 m/s. The runout and low-frequency suspension motion have been suppressed by filtering the data using a five-pole high-pass filter.
Butterworth filter with a 20 kHz cutoff frequency. The slider position is depicted for a 1 msec. time segment, and it is clear that the slider responds to contact in an elliptical path. As the slider moves vertically, it is also moving in the down-track direction. Because the ellipse is nearly circular, the magnitude of motion in the two directions is similar and nearly 90 degrees out of phase.

![Fig. 1 Phase plot of slider motion as it makes contact at 21.3 m/s viewed from the side elevation.](image1)

At three of the test velocities, the motion was elliptical. The repeatable portions of vertical and down-track position data were obtained by performing a least-squares fit using a sinusoidal function. Depiction of the repeatable portion is shown in Fig. 2 for the three velocities indicated. When the slider makes contact at 23.9 m/s, and as the velocity decrease, the down-track component becomes larger.

![Fig. 2 Phase plot of the repeatable, harmonic slider paths for 23.9, 21.3, and 16.0 m/s.](image2)

To compare the magnitude of motion in each direction and to illustrate how head-disc interference changes the relative magnitudes, we calculate the standard deviation of the position in each direction and plot it against the expected interference in Fig 3. We estimate the interference by using the decrease in fly height with linear velocity (0.53nm/m/s) and the observed touch-down velocity, 24.5 m/s. Generally, as the interference increased, the amplitude of motion in all directions increased. At all interference levels except 8nm, vertical motion was the largest. At most interference levels, down track motion was nearly as large as vertical motion and surpassed it at 8nm of interference. Notably, down-track motion increased almost linearly with interference, which suggests that down-track motion is an indictor of friction forces. Dynamic friction has been shown to increase monotonically with interference in this velocity regime [1], suggesting that the down-track motion arose from friction. As expected from these zero-skew angle experiments, off-track motion was the smallest of the three at all interference levels.

![Fig.3 Plot of one standard deviation of vertical, off-track, and down-track motion as a function of interference level.](image3)

The application of this new technique for characterizing down-track motion clearly shows that motion in all three directions is significant and in some cases down-track motion is larger than vertical motion. These measurements indicate that the down-track motion induced by friction cannot be ignored in the analysis of slider response to frictional forces. We have illustrated how slider-disc contact can give coordinated, periodic motion in several directions, producing elliptical slider paths. We have quantified the repeatable and non-repeatable components of this motion and have demonstrated that the amount of down-track motion increases with the level of head-disc interference. Further application of this technique could lead to developments in contact and intermittent contact recording by giving a more complete view of energy transfer mechanisms in the disc-slider-suspension mechanical system.

REFERENCES