Study of Head Disk Interface Characterization using Touchdown Sensor and Electro-Magnetic Signal in Hard Disk Drives

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With the introduction of thermal fly-height control sliders, the local head-disk clearance can be reduced to a range from around ten nanometers to contact. This actively controlled touchdown has been used as a way to study the head disk interface (HDI), the characteristics of which greatly affect the areal density and reliability of drives. In this paper, a high spatial resolution touchdown study is performed at the drive level using touchdown sensor signals and head media spacing signals. Different flying stages including passive flying, touchdown transition and over push modulation are identified from the experimental results. Correlation between the aforementioned signals at the passive flying stage is found to represent a disk surface property. The passive flying stage and over push modulation stage of touchdown are further analyzed in both the time and frequency domains. By establishing a correlation between fly height and the temperature response we can provide insight into the heat transfer model for the HDI.

Index Terms **— touchdown stage identification, touchdown sensor, head media spacing signal, head-disk interface**

I. Introduction

The expanding demand for data storage has led to the necessity of increasing the areal density in hard disk drives (HDDs), which in turn, requires the flying height of the air bearing slider that carries the read/write transducer to decrease from tens of nanometers to only a few nanometers[1,2]. Thermal fly-height control (TFC) sliders are widely used in current HDDs because of their capability to reduce the local spacing between the head and disk in a small region around the transducer while maintaining the spacing greater than 10nm over the rest of the slider. In this approach, the head disk interface (HDI) is not significantly affected by the inter-molecular forces between the slider and disk. With the TFC slider, the flying height of the slider can vary from its designed value to contact. Controlling the flying-height of the slider can provide insight into the characteristics of the HDI. At the component level, thermal protrusion induced slider-disk contacts have been studied theoretically, experimentally and by simulations. Acoustic emission (AE) and laser Doppler vibrometer (LDV) measurements are used to observe the slider's dynamics at disk proximity and contact [3-5]. In these studies, the AE sensor detects contact-induced elastic waves and the LDV is used to measure the dynamic modulation in different locations and directions of the slider, including the trailing edge center, leading edge center and down track direction. Using these AE and LDV signals, researchers have well studied experimentally the HDI at the component-level.

In drive-level testing, however, the means to evaluate the HDI has been limited to head-media spacing (HMS) signals, servo control signals and external AE sensors. The HMS signal, which is calculated from the first and third harmonics of the read back signal by use of the Wallace equation, is one of the most important flying height measurement methods [6-9]. However, this signal only represents a relative flying height change and thus is not suitable for touchdown (TD) detection and analysis. Due to such limitation, there has been little detailed discussion about touchdown stage identification in drive-level testing.

The recently introduced touchdown sensor (TDS) (also known as embedded contact sensor or thermal asperity sensor) has provided another approach for the study of HDI dynamics. Shimizu and Xu, 2011, proposed the embedded contact sensor for defect mapping on disks. This sensor is a thin film element that changes its resistance in proportion to its temperature [10]. Through thermal-mechanical analysis, simulation and component level testing, we are able to identify different HDI characteristics including asperities, pits, lube moguls, disk clamping distortions and surface microwaviness [11-14]. However, there have been few reports regarding TDS response to HDI spacing and its application in touchdown stage identification in drive level testing.

In this paper, the correlation between the temperature signal from a TDS and the spacing signal from HMS are calculated and discussed. Different stages of touchdown are further identified in drive level touchdown detection from these signals in both the time and frequency domains.

II. Experimental Scheme

Experiments were performed on commercially available drives operating at 7200 rpm. The TDS signal was high-pass filtered so that only the AC component was recorded and analyzed. HMS and TDS signals were acquired using a LeCory 8620A oscilloscope.

In the experiments, the TFC heater power supply and oscilloscope were controlled by a customized MATLAB script to record the HMS and TDS data, which were both triggered by the disk spindle index signal. During each test, the TFC power was increased step by step and the HMS and TDS data were recorded in each step for further comparison. The length of each step covered at least one revolution of disk rotation.

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III. Results and Discussion

A. Correlation of HMS and TDS

When the head was flying with a TFC power lower than the touchdown power (TDP), a repeatable pattern of TDS signal (index triggered) was observed. By comparing the TDS and HMS signals for the same time interval, we can observe similarities between the wave forms (Fig. 1). To quantitatively measure the similarity and the relative phase difference, we calculated the correlation coefficient between the HMS and TDS data points at each phase shift step (Fig.2). In Fig.2, it is seen that at a certain phase shift, the correlation coefficient between the HMS and TDS signals reaches a maximum of 0.748, and this number decays rapidly when the TDS signal is shifted either forward or backward. A clear correlation can also be seen in a scatter plot of the TDS and HMS data points at the optimum phase shift (Fig.3).

FIG. 1 HERE
FIG. 2 HERE
FIG. 3 HERE

In Fig.3, both the TDS signal and HMS signal are linearly shifted and normalized so that their minimum value during measurement is zero and maximum values is one. The positive correlation indicates that the temperature of the head rises as the spacing between the head and disk increases. This correlation between the TDS and HMS signals can be explained by the heat conduction dynamics in the HDI: when the flying height rises, the air cooling effect is less prominent on the slider, resulting in a slight temperature rise of the TDS, which is detected as a rise in the TDS signal. Similarly, a reduction in flying height — represented by a fall in the HMS — enhances the effect of air cooling and thus leads to a fall in the TDS signal.

This correlation demonstrates the possibility of using the TDS to identify and measure the HDI characteristics including disk microwaviness and lube moguls. This result coincides with the result reported by Xu et al [14].

B. TD stage identification

At different levels of TFC power, the HMS and TDS signals showed different patterns (Figs. 4 (a)-(c)). All of the HMS and TDS signals in Fig.4 were triggered at the same wedge on the same cylinder. Due to technical limitations, the signals were not acquired simultaneously.

FIG. 4 HERE

(a). Passive flying stage

In this stage, the HMS and TDS signals are both stable and repeatable and display irregular wave patterns (Fig.4 (a)). They both are related to the disk surface properties and correlate with each other. As the TFC power was increased, the amplitude and standard deviation of the TDS signal was observed to increase exponentially while the amplitude of the HMS signal remained almost unchanged (Fig.5). The passive flying stage corresponds to a TFC power from 0% TDP to around 95% TDP.

FIG. 5 HERE

(b). Transitional stage

When the slider was flying at proximity, a transitional stage could be observed. In the transitional stage, the HMS signal showed a relatively low frequency oscillating pattern added to the original HMS signal that shows disk surface information. The TDS signal at this stage also shows a ringing effect at the same frequency (Fig.4 (b)). Since the HMS signal is only related to the head-disk clearance, this wave pattern indicates that the head starts a vertical vibration in the transitional stage And the amplitude of vibration is still comparable with the surface microwaviness. In the TDS signal, however, the irregular wave pattern representing disk surface information is replaced by the modulation. This is probably because the temperature change caused by contact is much larger than the temperature change due to surface microwaviness and moguls and the earlier pattern is suppressed. From the HMS signal together with the TDS signal, it can be inferred that the ABS modulation starts in this stage, but the amplitude is much smaller than in the next stage. It may be explained that the head is only in contact with the disk in some isolated regions instead of during the whole revolution, resulting in a comparably smaller amplitude of modulation. This stage usually appears when the TFC power is between 95% TDP and 110% TDP.

(c). Over push modulation stage

For the case of the TFC power above the transitional stage, apparent modulation can be observed from both the HMS and TDS signals. The HMS signal reveals periodic spikes, meaning that the head is bouncing on the disk surface. Between the HMS spikes, wave patterns of the disk can still be observed. In TDS signal however, the wave pattern is no longer observable (Fig.4 (c)). A possible explanation is that the contact-generated heat contributes much more to the temperature change than the microwaviness-generated air cooling effect. It was also observed that the frequencies of the TDS and HMS modulations increase with the increase of TFC power, indicating a change in the air bearing surface (ABS) modulation modes. It can also be noted that in Fig.4 (c), the TDS signal shows a beating effect, meaning that at least two modulation frequencies are present. This modulation stage has also been reported by Chen et al [3,4].

FIG. 6 HERE

In Fig. 6, the aforementioned stages can also be identified:

(a). When the TFC power is lower than 95% TDP, no obvious frequency exists in the frequency spectrum.

(b). A broad band amplitude rise in the frequency spectrum before touchdown corresponds to the transitional stage of TD.

(c). A modulation frequency and its 2^{nd} and 3^{rd} harmonics rise as the TFC power increases. More peaks in the frequency spectrum appear later, resulting in the beating effect in the time domain in Fig. 4 (c).

IV. Conclusion

In this paper, drive level touchdown tests with high spatial resolution data acquisition were performed and were found to be an effective method for investigating different touchdown stages. Passive flying, transitional and modulation stages were identified by TDS and HMS measurements from both the time domain and frequency domain. In the passive flying stage, both signals were repeatable and a correlation was observed between the two signals. This correlation proved that the TDS responds to the surface characteristics actively and sensitively. In the transitional stage and modulation stage, both the TDS and HMS lost their repeatability in the time domain due to modulation, but the frequency spectrum remained repeatable under the same TFC power. Along with the increase of TFC power during over push, the modulation frequency also increased, which was due to the change of ABS modulation mode.

Establishing a correlation between fly height and the temperature response can provide insights into the heat transfer model for the HDI. Meanwhile, identifying different TD stages with the TDS response can provide supporting details for failure analysis and tribology design.

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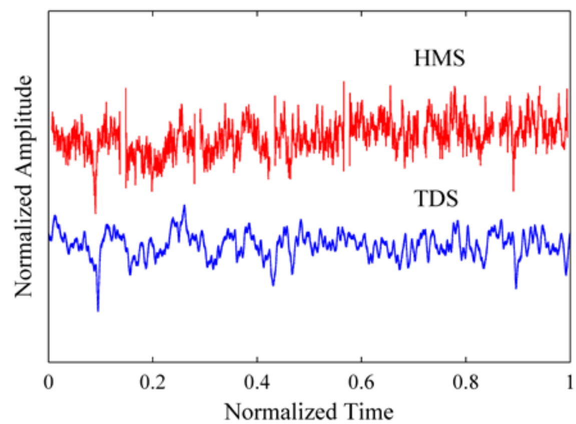

Fig. 1 HMS and TDS signals during passive flying

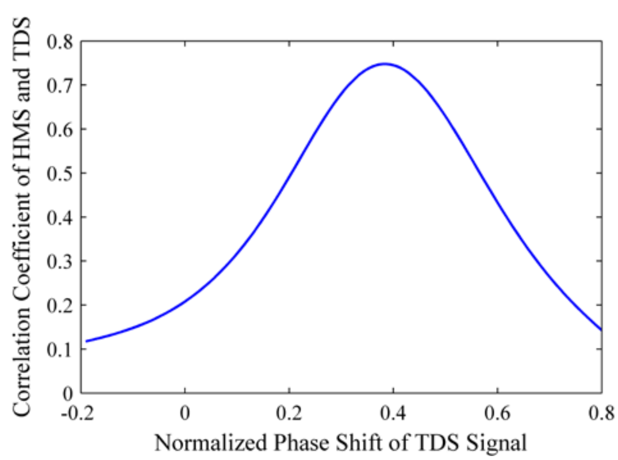

Fig.2 Correlation coefficient between HMS and TDS signal with different phase shift

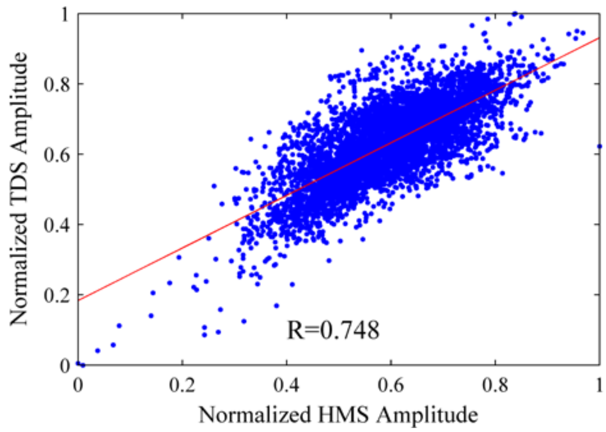

Fig.3 HMS and TDS signal correlation at the best phase shift

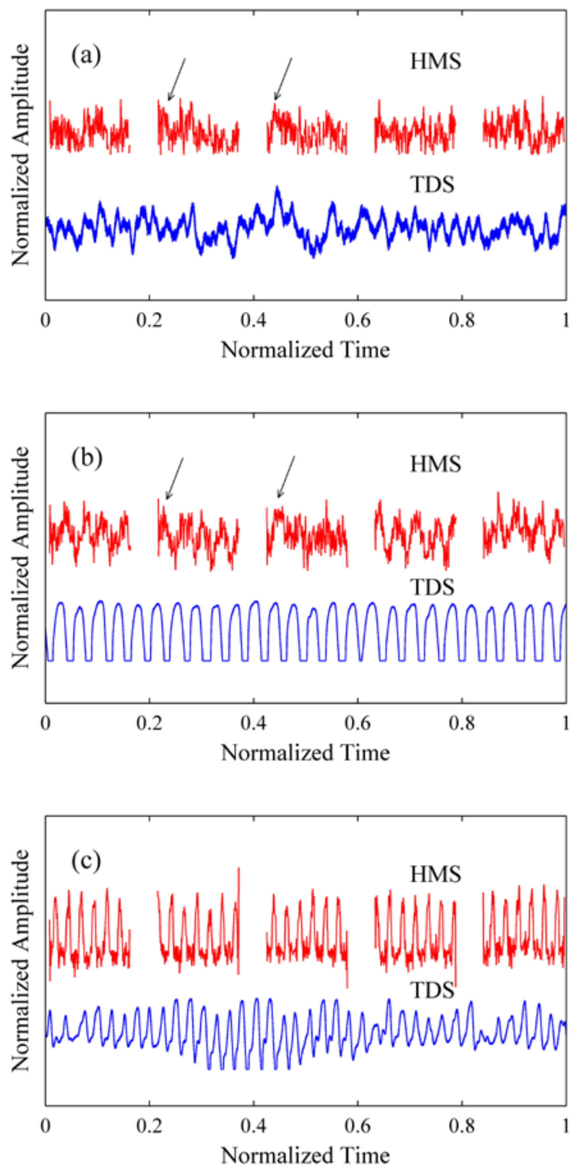

Fig. 4 HMS and TDS signal comparison at different stages: (a) passive flying stage, (b) transitional stage and (c) modulation stage.

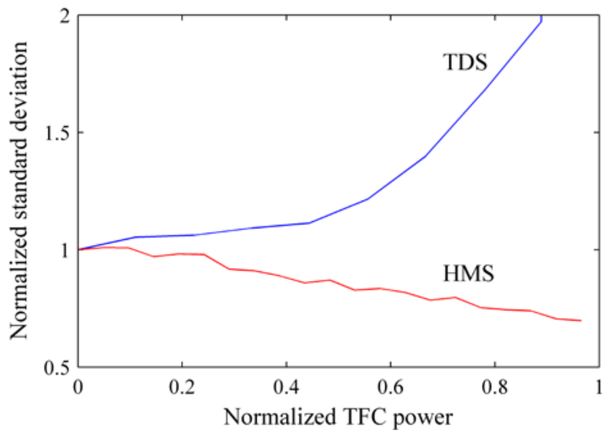

Fig.5 Standard deviation of HMS and TDS signal as TFC power increases during the passive flying stage

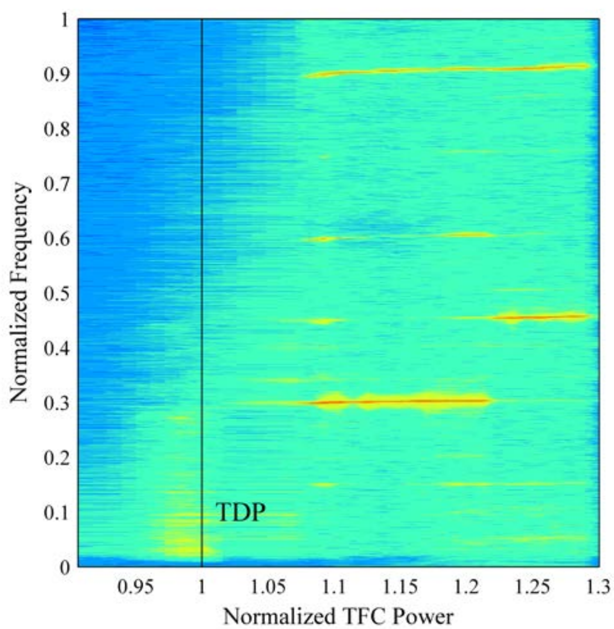

Fig. 6 Normalized TFC power-frequency spectrum contour of touchdown sensor signal