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Quantitative identification of slider nanoscale wear based on the head-disk interface dynamics

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ABSTRACT

To reveal the mechanism of head-disk interface wear behaviors, this paper proposed a novel transformation on slider's vibration signals, which was derived to having a strong correlation with the slider wear. Based on the modal analysis, the high-frequency component was regarded as the air bearing mode while the low-frequency corresponds to the structure (suspension related) mode. Both structure and air bearing mode dissipated energies were extracted and the correlation analysis between the energy and wear volume verified the proportional relationship. Finally, regression analysis was employed to establish the linear model for wear and energy. This paper helps understand the wear mechanisms of slider from the interface dynamics response's view, and then provides a novel quantitative analysis approach for slider wear identification.

1. Introduction

In recent years, the hard disk drive (HDD) industry and researchers have attempted to increase the storage density of HDDs. A high storage density requires the reduction of the physical clearance between the magnetic head (slider) and the disk. Thermal flying height control (TFC) is the most commonly used technology in the industry, and it enables an embedded heater around the slider's trailing edge to expand towards the disk when electric power is applied [1]. During the whole process of reading/writing, only a tiny part of the slider protrudes onto the disk, while the rest of the slider is lifted by air flows. Reading and writing operations can only be carried out when a suitable clearance is set. Currently, the physical clearance between the slider and disk is close to 1 nm, as the storage density is approximately several Tb/in^2 [2]. At such a thin clearance, the intermittent or continuous contacts are unavoidable. Under severe operating conditions, e.g., shock, vibration, or a high temperature, the slider and disk may suffer wear [3–5], corrosion, and even complete destruction due to strong interfacial interactions [6–9]. Wearing is one critical problem regarding HDD reliability except for the mechanical operational shock [10–13]. As a typical elastoplastic semi-infinite medium system, smooth head-disk surfaces lead to an increase in adhesion, friction and interface temperatures, and closer flying heights leads to occasional rubbing of high asperities and increased wear [14]. To resolve the friction and wear issues, the appropriate selection of interface materials and lubricants, the dynamics control of the head and medium have been researched a lot. Thermodynamics analysis, finite element analysis and a series of research methods have been used for sliding contact research [15–17]. However, the relationship between the slider dynamics and wear/damage during head-disk contact is not fully understood yet. In this paper, we mainly focus on exploring the wear mechanism of slider.

Wear is the slow degradation of the slider and disk. According to the Archard law (1), slider wear may be influenced by the normal load, relative sliding speed, the surface topography, environmental conditions, materials, and design [18]:

$$V = \frac{k \cdot L \cdot W}{H} \tag{1}$$

where V is the wear volume, k denotes the constant related to the surface hardness, L is the sliding distance, W is the normal load, and H is the hardness of contacting surface. For slider wear research, the contact depth were usually controlled at lubricant layer and the hardness item can be approximated as a constant value for ease of application [3].

$$V = k \cdot L \cdot W. \tag{2}$$

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Numerous studies have investigated the relevant factors and enhancements of the Archard law in order to better understand the nature of wear behavior. Normal load and surface topography are of more interest than the other factors [3,19]. For example, a heavier load may induce a larger contact area, and further result in more serious wear. However, the transient dynamics were not considered in regards to the wear propagation in aforementioned studies, which might vary significantly with a rugged surface. Though the response frequency varies as a function of the TFC power has been investigated by many researchers [20–23], the relationship between the slider dynamics and wear amount is still not clear yet. Nevertheless, the slider/disk interactions excited by the head-disk contact do contain rich useful information that can be used to reveal the relationship between wear and dynamics. Besides, the vibration of slider is acquirable with the help of non-contact measurement techniques. In our previous study, laser Doppler vibrometers (LDVs) were used to monitor the head-disk interactions which offers an effective way to measure the contact dynamics during different contact stages [24,25]. Based on response analysis, the frequency spectrum of vibration signal plays a paramount role in revealing the relationship between the slider interfacial dynamics and wear behaviors [26,27].

The aforementioned studies have provided valuable guidelines for understanding the wear performance of head-disk interface based on the vibration analysis. However, there is still a lack of quantitative analysis besides qualitative analysis. Back to the Archard equation (2), normal load W is the key parameter in wear evaluation that decides the wear volume directly. In order to obtain the contact force of slider-disk interface, a lot of studies have been carried out. Frequency response functions (FRF) was a feasible approach for identifying the contact force [28], in which finite element method could calculate the modal frequencies and experimental data was able to determine the damping parameters of FRFs [29,30]. However, a small error in modal frequencies can result in a large bias in the identified forces which leads to a significant accuracy requirements for finite element model and experimental data. What's more, the different expression of FRFs for different sliders also limits the generalization of FRF approach to a certain extent.

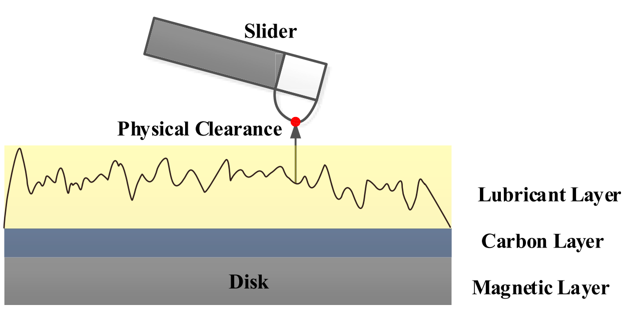

Fig. 1. Scheme of slider-disk interface.

To make up for that, this paper expands a novel perspective to understand the effectiveness interfacial dynamics has during the slider wear stage. By analyzing the vibration signals obtained with LDVs and applying some transformation tricks, the slider's interfacial dynamics is proved to be directly related to the contact force. Combine with Archard law, the relationship between vibration spectrum and wear behavior is established. The phenomenon of two stages of the touchdown process has been observed in many researches [2], [31]. Based on the experimental and simulation study of touchdown dynamics, the low frequency vibration was a suspension mode excited by the lubricant and the high frequency vibration was the second pitch mode of the slider air bearing excited by the contact between the slider and the disk [5]. In our experiment, the low frequency located at ~75 kHz and we defined the suspension mode as structure mode, the high frequency corresponded to ~320 kHz and was defined as air bearing mode [24]. According to our results, the air bearing mode, recognized as high-frequency components, is much more relevant to slider wear than structure mode. Moreover, a qualitative relationship is modeled by correlation approach that the wear volumes are supposed to be identified directly by means of head-disk interfacial dynamics. This paper helps to understand the wearing mechanisms of slider from a view of vibration analysis, and thus hope to provide a new approach for slider wear behavior quantitative identification.

2. Vibration analysis

The slider-disk interface is illustrated as Fig. 1. As the decrease of physical clearance, slider contacts with lubricant layer, carbon layer gradually and four different stages were divided according to the relative clearance of slider [24]. Due to the roughness of the disk surface, friction is unavoidable when slider touching with disk and vibration generates accordingly.

Now consider the slider-disk interface separately, which is equivalent to a two-dimensional suspension air bearing model as shown in Fig. 2. In which, F_{ar} is the nonlinear air-bearing force, F_s is the adhesive force, F_c is the contact force of the interface, and Q is the friction force. As illustrated in Refs. [32,33], the F_{ar} and F_s would increase sharply with the decreasing of flying height and play a dominant role in slider vibration. Denote the vibration in vertical direction as $x(t)$, the motion equation can be written as

$$m\ddot{x} + c\dot{x} + kx = F_a \tag{3}$$

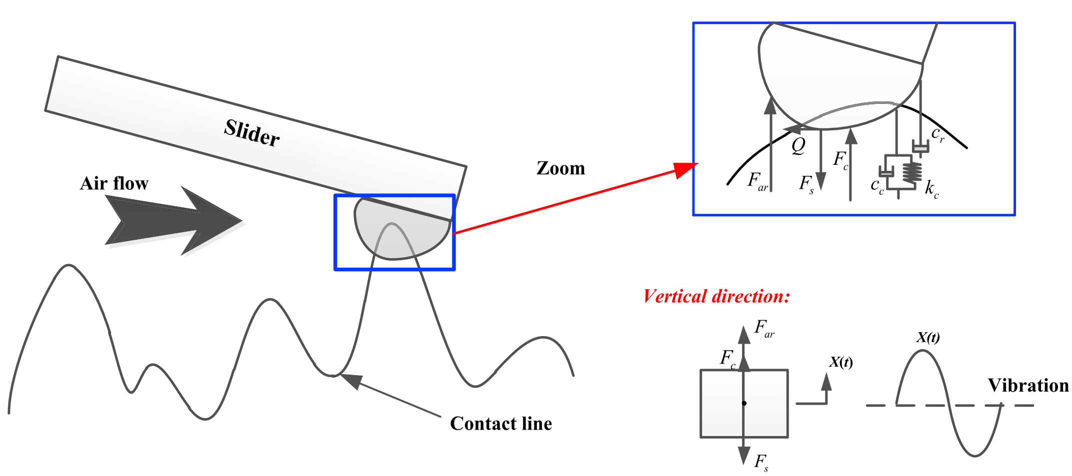

Fig. 2. Schematic of 2-DOF dynamic contact model.