Active Control of Friction between Head-Slider and Disk for Magnetic Memory Devices(磁気記憶装置のヘッドスライダーとディスク間の摩擦のアクティブ制御)

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論　文　内　容　要　旨

Chapter 1. Introduction

Ever increasing recording densities require that a slider in hard disk drive must have an ulra-low flying height. A flying height of approximately 6 nm is required to achieve a recording density of 100 Gbits/inch^2. It is obvious that at such a low flying height, deviation in flying height of individual sliders due to manufacturing tolerances will become a big issue. That is, a ±2 nm deviation of flying height would be larger, and a reduction in the deviation either results in a poor yield or significantly increases production costs. Active sliders have been fabricated to adjust flying height for contact recording or load/unload on demand system. Therefore, an active-head slider, which allows the flying height to be adjusted individually and the manufacturing tolerances to be compensated, has been developed. This slider carries a unimorph piezoelectric micro-actuator and its flying height can be adjusted to a specified value on demand.

When adjusting the flying height of the active-head slider toward the disk surface, it is very likely that the slider will contact the disk surface. Furthermore, since an atomic-level smooth disk is necessary for such a low flying height, head-disk contact may cause large friction and increase the risk of a head crash. Reducing friction and minimizing the damage due to slider-disk contact are serious issues regarding an active-head slider.

Several researchers have reported that it is possible to effectively reduce friction force at the head-disk interface by giving the disk a texture. A slider texture can also reduce friction when the slider contacts the disk. However, as mentioned above, a disk texture prevents a slider flying over the disk at such a low flying height. Regarding the slider texture, it is difficult to ensure that the peaks of the texture are closer to the disk than the read-write element and spacing loss due to texture is minimized.

In response to the above-mentioned issues, a novel method that enables an active-head slider to approach a disk surface safely with micro-vibration is proposed to reduce friction against slider in this study. The feasibility and effectiveness of this new method is discussed. An active-head slider is designed and fabricated. Friction control and flying height adjustment is discussed based on the fundamental static and dynamic characteristics of the fabricated active-head slider.

Chapter 2. Basic study of friction control by micro-vibration between head-slider and disk

To identify the possibility of application of this method to a hard disk drive, a model active slider was introduced to basically study friction control by micro-vibration in this chapter. The effect of micro-vibration on friction between slider and disk in hard disk drive was investigated. Friction decreases with increasing the amplitude of vibration of a head slider. It is found that the micro-vibration can reduce friction, especially, when the disk is smooth and the load is light. It is also found that a certain vibration amplitude is necessary to reduce friction significantly. In addition, the resonant frequency of the piezo-actuator is found to shift to higher at higher suspension load. This frequency-shift is considered to be an important factor in optimizing the drive frequency of the actuator.

Chapter 3. Micro-vibration effect on friction between head and disk under micro-load

In this chapter, the preliminary experiments based on the model head were conducted to study the influences of the shape parameters of the contact pads and the influences of roughness on friction reduction by micro-vibration under micro-load. The results indicate that friction decreases with increasing the micro-vibration amplitude. For this model head, 360 nm is the optimum amplitude for friction reduction when a slider comes in contact with the disk surface. At an optimal amplitude of micro-vibration, roughness hardly affects friction, while roughness affects the friction force significantly without micro-vibration. It is also found that an amplitude of vibration larger than 360 nm is necessary to effectively reduce friction force under a 0.25 mN load for a smooth disk with surface roughness of 0.3 nm, as shown in figure 1.

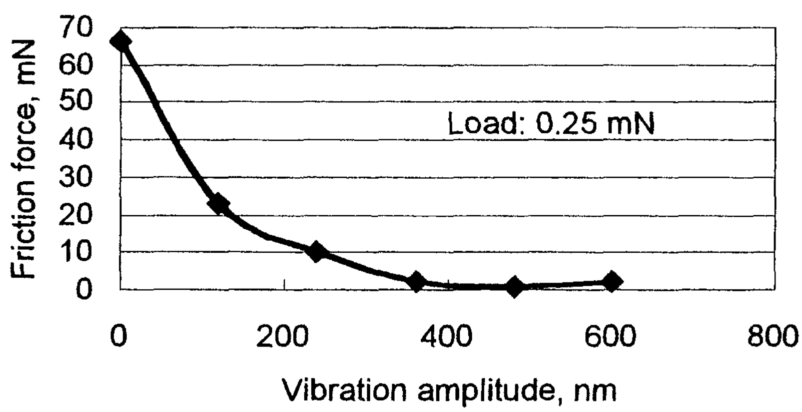

Figure 1 Friction force as a function of vibration amplitude under a 0.25 mN load
(Disk surface with roughness of 0.3 nm)

Chapter 4. Design and fabrication of pico-sized active-head sliders

In this chapter, pico-sized active-head sliders were designed and fabricated, based on the results from chapter 2 and chapter 3. The purpose of this chapter is to design and fabricated a pico-sized active-head slider for flying height adjustment and friction control. The active-head slider that can finely tune the flying height of a read-write head with a micro-actuator for the purpose of abandoning the extra flying height clearance due to manufacturing tolerances and environmental variances is designed to achieve a lower flying height. A prototype active-head slider with size of 1.4 mm (L)×1.0 mm (W)×0.3 mm (H) is fabricated by using the MEMS process for the following evaluation in the next chapter as shown in figure 2.

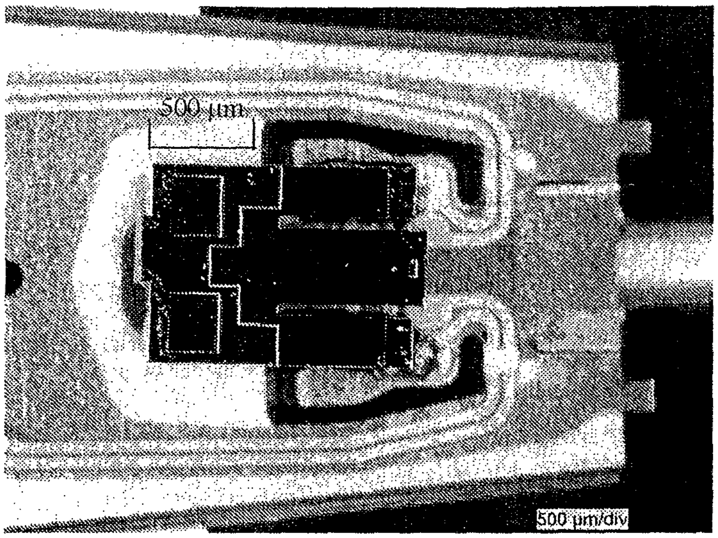

Figure 2 Fabricated pico-sized active-head slider

Chapter 5. Static and dynamic characteristics of active-head sliders

In this chapter, the static and dynamic characteristics of fabricated active-head sliders were evaluated. The purpose of the chapter is to obtain the fundamental data for flying height adjustment and friction control. Static and dynamic characteristics of such active-head sliders have been further investigated by laser Doppler vibrometer and Wyko surface profiler in order to obtain the fundamental data for flying height control from the viewpoint of friction reduction and head crash prevention. It is found that the normalized stroke of the actuator is 5.2 to 6 $nm/V/mm^2$ without flying over the disk. Frequency characteristics of fabricated active-head sliders have been confirmed. The fabricated active-head slider shows good frequency response without inducing large vibrations of an air-bearing pad. The resonant frequency of the fabricated active-head slider is 243 kHz, which is enough for tracking the disk surface when vibration is applied to control the friction force. Frequency is set at 250 kHz for friction control by micro-vibration.

Chapter 6. Friction control and flying height adjustment of active-head sliders

In this chapter, the flyability, flying height adjustment and friction control using fabricated active-head slider were investigated by means of Dynamic Flying Height Tester (DFHT). It is found that flying height at active-pad (A) can be reduced from 24 to 10 nm by applying 10 V to the actuator as shown in figure 3. The flying height adjustment can only be applied at the active-pad (A) and has no effect on the dynamic flying characteristics of the whole slider (air bearing pad B and C) as shown in figure 3. Furthermore, micro-vibration of active-pad is effective in avoiding the high friction force and the head crash when active-pad comes in contact with the smooth disk surface during the flying height adjustment as shown in figure 4

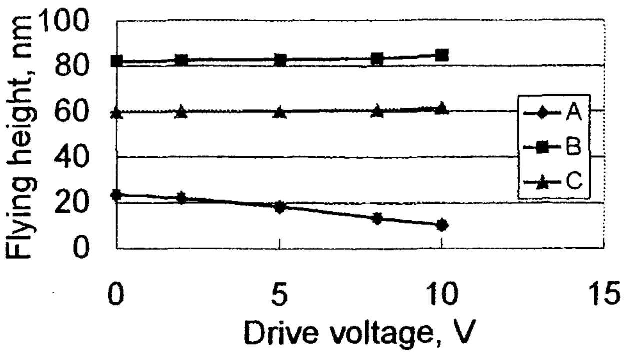

Figure 3 Flying height and drive voltage

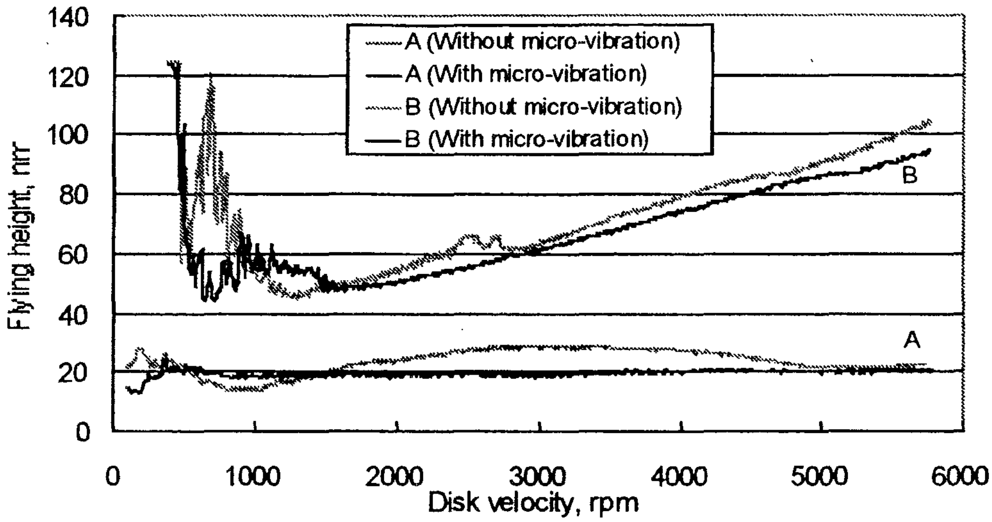

Figure 4 Flying height at active-pad (A) and air bearing pad (B) with and without vibration as a function of velocity on glass disk with roughness (Ra) of 0.6 nm

Chapter 7 Conclusions

This chapter presents the conclusions of this thesis. To achieve a high recording density and a low flying height for magnetic memory devices, active-head sliders are developed. These sliders carry a piezoelectric actuator for friction control and precise control of flying height. The possibility and effectiveness of friction control by micro-vibration are approved. Micro-vibration is effective to avoide a high friction force and a head crash when a head comes to contact with smooth disk surface during flying height adjustment.

論文審査の結果の要旨

磁気ディスク装置の面記録密度は年率 100%の勢いで増加してきており、現在は磁気ヘッドスライダーの浮上量を 10nm 以下に低減することが求められている。この場合ナノメータオーダの低浮上量を依持することの困難さに加えて、ヘッドスライダーとディスクの接触が不可避的に発生することによる摩擦力の制御が信頼性確保のために極めて重要になる。このような背景の下に本研究はマイクロ圧電アクチュエータをヘッドスライダーに組み込み、その浮上量を正確に制御すると共に振動を制御することにより摩擦力を効果的に低減できることを実験により明らかにした。その結果、摩擦のアクティブ制御のコンセプトに基づきアクティブピコスライダーを設計製作し、その有効性を確認した。本論文は、この研究成果をまとめたもので、全編 7 章よりなる。

第 1 章は緒論であり、本研究の背景及び目的を述べている。

第 2 章では、従来型のサスペンションにマイクロ圧電アクチュエータを組み込んだモデルのアクティブヘッドスライダーを作製し、ヘッドスライダーに加える微小振動と摩擦の関係を調べ、摩擦がヘッドスライダーの振幅の増加と共に減少し、ヘッドスライダーの共振振動数の近傍において効果的に減少されること、及びこの効果はディスクの表面粗さが小さいほど大きくなることを明らかにしている。これはアクティブピコスライダー設計のための基礎知識として重要である。

第 3 章では、接触面に垂直方向に正確に微小振動させることのできるモデルヘッドと、その接触状態を観察することのできる装置を作製し、これを用いてヘッド表面のテクスチャー形状とディスク表面の粗さ及び潤滑状態が摩擦と振動の関係に及ぼす影響を調べている。その結果、荷重が 1mN 以上の領域においてテクスチャー形状の影響が小さいこと、微小振動が振幅 360nm 以上において摩擦のディスクの表面粗さ敏感性がなくなることを明らかにしている。これらはアクティブピコスライダーの設計ための基礎知識として重要である。

第 4 章では、第 2 章と第 3 章の結果に基づき、マイクロ圧電アクチュエータを組み込んだ 1.4mm(L)×1.0mm(W)×0.3mm(H)の大きさのアクティブピコスライダーを設計し、試作プロセスの選定と試作を行い、製作可能であることを実証している。ここに提案された設計のコンセプトと製作可能の実証は重要である。

第 5 章では、第 4 章において作製したアクティブピコスライダーの静特性と動特性を種々の観点から調べ、それが 5.2~6nm/V/mm^2 変位と 243kHz の共振周波数を有し、マイクロ圧電アクチュエータによるナノメータオーダ変位制御と摩擦制御が可能であることを明らかにしている。

第 6 章では、ディスクに対するアクティブピコスライダーの浮上量及びディスクに接触した場合に発生する跳躍の微小振幅加振による制御性を実験により調べ、4200rpm のディスク回転数において、浮上量を 10nm に保てること、微小振動により大きな跳躍を効果的に避けられることを明らかにしている。これらは世界で初めての先端的成果であり非常に重要な知見である。

第 7 章は結論である。

以上要するに本論文は，次世代磁気記憶装置のヘッドスライダーとディスク間の摩擦制御のためにマイクロ圧電アクチュエータを組込んだアクティブピコスライダーを開発し、製作の可能性を実証し、試作したアクティブピコスライダーにより摩擦の効果的な制御が可能であることを明らかにしたもので、機械工学ならびにトライボロジーの発展に寄与するところが少なくない。

よって、本論文は博士（工学）の学位論文として合格と認める。