Optimized Design of Heaters for Flying Height Adjustment to Preserve Performance and Reliability

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We developed a thermal flying-height control (TFC) slider to control the flying height of magnetic recording heads. The slider basically consists of a small heater fabricated near the read/write element. This study discusses the effect of heater size and heater location on the change in the flying height at the read/write element. We also discuss the resulting temperature rise due to the additional heat applied by the heater. Specifically, we have found that small heaters generally resulted in lower heater power per unit change in the flying height and lower head temperature rise per unit change in the flying height. In terms of heater location, we have found that a heater closer to the air-bearing surface (ABS) also tends to result in a larger change in the flying height because of the larger protrusion shape. However, the head temperature rose significantly. Therefore, shorter ABS/heater distance was a trade off lower power against higher rise in head temperature. We concluded that smaller heaters and the shorter ABS/heater distance are better as long as head reliability is ensured.

Index Terms—**Flying height, magnetic head slider, microactuator, thermal protrusion.**

I. INTRODUCTION

SATISFYING the continuing need to increase the capacity of hard disk drives (HDDs) absolutely requires reducing the flying height at the read/write element. Currently, the obstruction to decreasing the flying height is the margin for variations and changes in flying height that are caused by manufacturing tolerance, environmental variations, and write-current-induced protrusions.

To achieve minimization of the margin, sliders that include microactuators have been proposed for adjusting flying height [1]–[7]. In these approaches, the most feasible one is that of controlling flying height at the read/write element with thermal expansion by having a heating element near the read/write element. Previous prototypes of this new technology, referred to as thermal flying-height control (TFC), have indicated its possibilities and provided a rough picture of expected performance [8]–[10]. Some of our simulation results seem to indicate that the location and the size of the heater significantly effect TFC performance [9].

In this study, we evaluated TFC prototypes in terms of the location and size of the heater element. Specifically, we measured the delta clearance at the read element per units of power consumption—the most important property of TFC sliders—and the rise in head temperature (delta T) that influences the reliability of magneto resistive (MR) sensors. In addition to reporting these measurements, we propose an optimized design for a heater without loss of the reliability.

II. EXPERIMENTS

A. Apparatus

A schematic view of the experimental setup is presented in Fig. 1. The disk and slider are set in a read/write spin-stand that consists of a spindle unit and a read/write unit.

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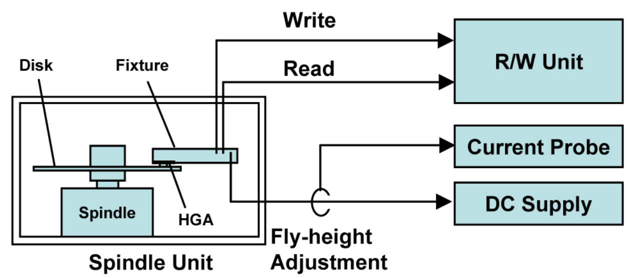

Fig. 1. Schematic view of experimental apparatus.

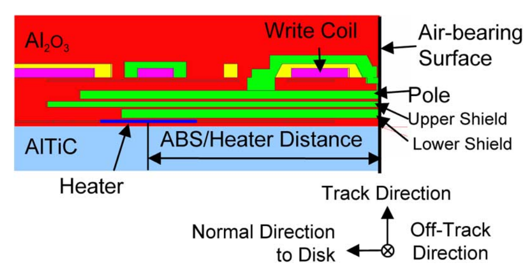

Fig. 2. Cross section of element.

B. Samples

In this study, we used pico sliders that included TFC heaters. The heater layer is separated from the read/write element to provide flexibility of trial heater design and to reduce the need for changes in the conventional element design (Fig. 2). The heater material was NiCr.

Here, we define the heater dimensions. As Fig. 3 indicates, we define the dimension of heater in the normal direction to the disk as its height. In the same way, we define the dimensions of the heater in the off-track and track directions as its width and thickness, respectively. In addition, the distance between the air-bearing surface (ABS) and the center position of the heater is defined as the ABS/heater distance.

We prepared five types of samples for this study in terms of heater location and size. The dimensions of those types are listed in Table I.

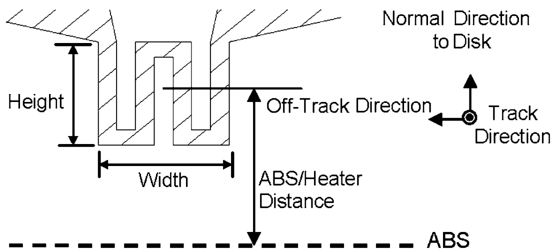

Fig. 3. Dimension of heater.

TABLE I
LIST OF HEATER TYPE

Type	ABS/Heater Distance (μm)	Size of Heater (μm)
A	25	H18.3 x W22.0 x T0.12
B	15	H18.3 x W22.0 x T0.12
C	40	H18.3 x W22.0 x T0.12
D	25	H13.5 x W14.0 x T0.12
E	25	H36.6 x W44.0 x T0.12

C. Experimental Methods

1) Delta Clearance at Element: Dietzel *et al.* optically measured delta clearance due to a microheater near the read/write element [6]. On the other hand, the deformation due to TFC heater is too local to ignore the difference of delta clearance due to measurement location. So we measured Track Averaged Amplitude (TAA) as a function of heater supply and converted the obtained value into precise delta clearance at the read element by using Wallace's spacing loss formula. The power was supplied to the heater by a dc supply. The supply ranged from 0–40 mW. The write frequency was adjusted so that the wavelength was similar to sine wave. The velocity and the skew were 14.27 m/s and $-11.85°$ respectively.

2) Temperature Rise of Head: We measured the resistance of the MR sensor with a digital multimeter and converted it into the rise in temperature of the head by using the temperature coefficient of resistance. The heater was powered by the dc supply. The supply ranged from 0–50 mW. The velocity and the skew were 26.39 m/s and 0°, respectively.

III. RESULTS AND DISCUSSION

A. Delta Clearance at Element

In Fig. 4, arbitrary delta clearance at the element is plotted against ABS/heater distance. As we found from the simulation results, the closer the heater is to ABS, the larger delta clearance is. We consider that the main reason the shorter ABS/heater distance generates larger change in fly-height is that the ABS, namely the free boundary, causes some relaxation of stress due to thermal expansion, and this in turn increases the available displacement and causes a sharper protrusion shape. The sharper protrusion shape probably leads to a lower compensation ratio, that is, a larger delta clearance. We described the mechanism of flying-height compensation in detail [10].

The comparison of Type A, Type D, and Type E, including the different sizes of heaters, shows the effect of their size. The larger heater makes the delta clearance smaller. The narrow range of thermal expansion generates a large protrusion. In addition to this, the difference in the protrusion's sharpness probably affects the compensation ratio.

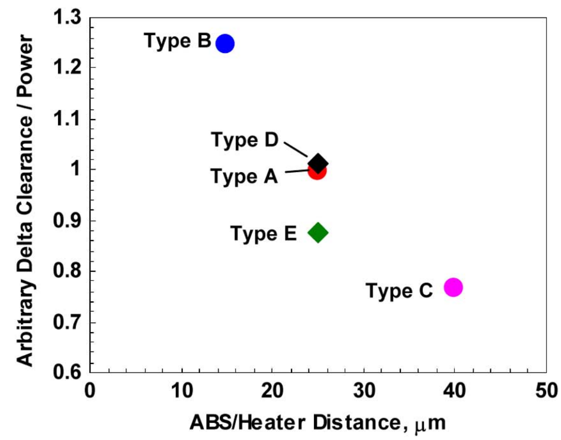

Fig. 4. ABS/heater distance versus arbitrary delta clearance per power.

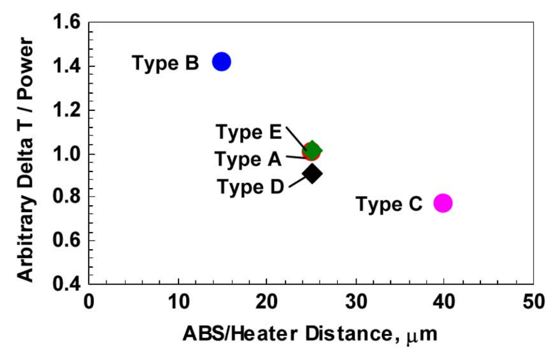

Fig. 5. ABS/heater distance versus arbitrary delta T per power.

B. Temperature Rise of Head

In Fig. 5, arbitrary delta T is plotted against ABS/heater distance. As we have learned from the simulation results, the closer the heater is to ABS, the larger delta T is. We see from the comparison of the results for Type A, D, and E that a larger heater generates larger delta T. It is reasonable to suppose that the concentration of heat is widened by the larger heater, and the increase in the breadth of heat distribution increases delta T.

C. Optimization of Heater Design

It is better for the TFC heater to consume less power, and desirable for the temperature rise of the head to be as small as possible to maintain the reliability of the MR element. In the foregoing section, we described the change in flying height and the rise in head temperature. However, from the viewpoint of low-power consumption and high MR sensor reliability, reducing power consumption of the heater and delta T of the head per units of delta clearance at the element is important.

Arbitrary power consumption and delta T per units of delta clearance at the element as a function of arbitrary ABS/heater distance is shown in Fig. 6. We can recognize from the plotted power consumption that the shortening of ABS/heater distance certainly reduces power consumption, but tends to increase the

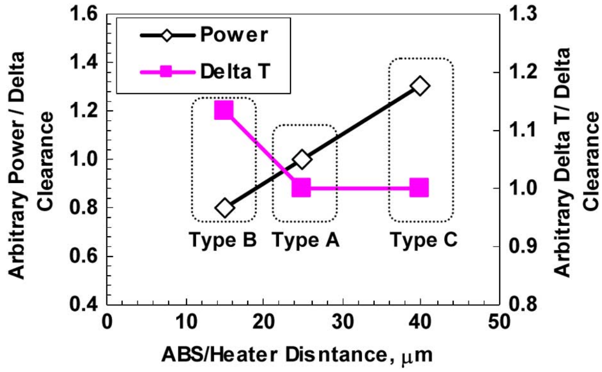

Fig. 6. Arbitrary power consumption and delta T per unit of delta clearance versus ABS/heater distance.

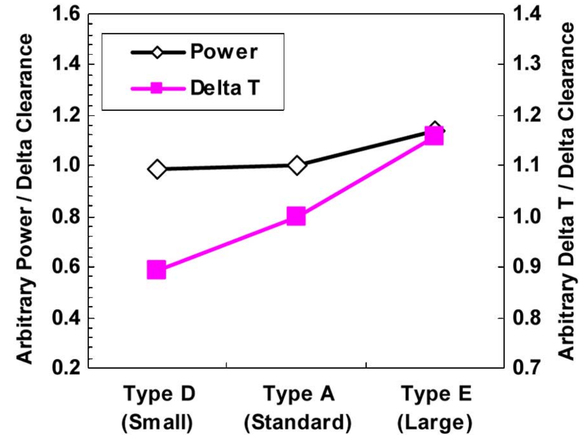

Fig. 7. Arbitrary power consumption and delta T per unit of delta clearance as a function of heater size.

delta T. In other words, reduced power consumption is a trade off against lower reliability of the MR sensor.

However, we should focus attention on the very little difference between Type A and C in delta T per unit of delta clearance. This fact reveals that keeping the heater as far away from the MR sensor as possible does not necessarily lead to high reliability of read element. In consequence, we concluded that Type A is in the optimum location.

Arbitrary power consumption and delta T per units of delta clearance at the element as a function of heater size is shown in Fig. 7. The downsizing the heater results in increased delta clearance and reduced delta T. Naturally, the performance of type B is the best. However, downsizing with constant heater resistance requires extremely fine heater wires. That is to say, the cross section of the wire becomes small. Therefore, the reliability of the heater will be extremely degraded because of the rise in temperature of the heater itself resulting from concentration of heat and increase of current density. The optimal heater size for better TFC performance and the reliability of the heater itself remain as matters to be investigated further.

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