The effect of write current on thermal flying height control sliders with dual heater/insulator elements

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Abstract The effect of write induced pole tip protrusion on the magnetic spacing of the head/disk interface has to be taken into consideration as flying heights approach the spacing regime of a few nano-meters. Thermal flying height control (TFC) sliders are presently in common use in hard disk drives to control the flying height at the read/write element during drive operations. In this paper the flying characteristics of TFC sliders with dual heater/insulator elements are investigated. Simulation results are shown for situations where the write current is “on” and where the write current is “off”. The effect of design parameters of two heater/insulator elements is studied to optimize the performance of TFC slider.

1 Introduction

In order to achieve areal densities beyond 1 Tb/in.², a stable head/disk interface at an ultra-low magnetic spacing is required for magnetic hard disk drives. Pole tip protrusion caused by the write current may lead to flying instability of the slider and to head/disk contact (Tian et al. 1997; Pust et al. 2002; Imamura et al. 2002; Xu et al. 2009; Song et al. 2008; Li et al. 2005). Thermal flying height control (TFC) sliders are presently in common use in hard disk drives to improve the flying characteristics of the read/write element. Numerical simulations have shown that TFC sliders with a single heater element embedded near the read/write element exhibit reduced flying heights at the reader and writer compared to sliders without any heater elements. Furthermore, simulation results indicate that a TFC slider with two heater/insulator elements achieves a larger flying height reduction at the read/write element than single TFC heater designs, keeping the power input the same for the two types of TFC sliders. In addition, the thermal actuation efficiency (ratio of flying height reduction to the maximum thermal protrusion) of the read/write element is found to be improved by the implementation of two heaters (Kurita et al. 2005, 2006; Suk et al. 2005; Juang and Bogy 2007; Li et al. 2009, 2010; Zheng et al. 2009).

In this paper, the flying characteristics of a typical TFC slider with dual heater/insulator elements are investigated numerically and compared with the flying characteristics of a slider without thermal flying height control. The flying height of the two types of sliders is evaluated for situations where the write current is “on” and where the write current is “off”. The design parameters for the dual heater/insulator elements, such as the location and the heat input of the two heaters, are optimized.

2 Numerical model

A schematic model of a TFC slider with dual heater/insulator elements is shown in Fig. 1. TFC heater 1 (red), with an insulator on the left (green), is located near the read element. TFC heater 2 (red) has an insulator (green) on the right and is close to the write element. The distance from heater 1 and heater 2 to the air bearing surface (ABS) is denoted as ‘D1’ and ‘D2’, respectively.
An iterative solution is required to obtain the reduction in flying height caused by the thermal protrusion (Kurita et al. 2005). The solution proceeds as follows. First, the air bearing pressure and the flying height of the slider are obtained by solving the equations of motion of the slider and the Reynolds equation simultaneously. Then, the heat transfer coefficient between the slider and the air bearing is determined (Juang and Bogy 2007; Li et al. 2009, 2010). The results serve as boundary condition at the ABS for the thermal analysis. The thermal deformation causes a protrusion of the read/write element, which, in turn, alters the geometry of the ABS. A new air bearing calculation is performed to obtain the updated pressure distribution and flying height. Iteration continues until convergence is reached, i.e., until the change in flying height at the read/write element between succeeding iterations is \( \leq 0.1 \) nm.

### 3 Simulation result

#### 3.1 The effect of write current

Figure 2 shows the profile of thermal protrusion along the center line of the slider for the cases that (a) only the writer is “on”, (b) the writer is turned “off” but the two heaters are “on” with equal heat input (i.e., \( P_1 : P_2 = 1:1 \), where \( P_1 \) and \( P_2 \) are the power inputs of heater 1 and heater 2, respectively), and (c) both the writer and the two heaters are “on”. The curve “Writer + DH” is displayed in Fig. 2 by adding the values of thermal protrusions of case (a) and (b) mathematically. Figure 3 shows the corresponding flying height profiles along the center line of the slider for the above four cases. In addition, the “original” flying height profile of a slider without any heat input is shown in Fig. 3 for comparison.

We observe from Fig. 2 that a small thermal protrusion is present if the write current is turned “on” without the heaters. A much larger thermal protrusion is obtained if the heaters are “on” without the writer being operating. The thermal protrusion is the largest among the three cases when both the write element and the heaters are turned “on”. However, this result (“Writer + DH ON”) does not agree with the mathematical sum of the thermal protrusion profiles of case (a) and (b), which is indicated as “Writer + DH”. This is due to the nonlinearity of the air bearing. The maximum difference between the two profiles is 0.5 nm.

Figure 3 shows that a small decrease in flying height occurs if the write element is turned “on”. A much larger decrease is observed if the dual heater elements are “on”. The largest decrease in flying height is observed for the case that both the heaters and the write element are turned “on”. This case leads to an additional decrease in flying height of 0.7 and 1.3 nm at the read and write elements, respectively, compared to the case that only the heaters were turned on. However, the thermal actuation efficiency...
at the reader reduces from 61%, when both the heaters and the write element are “on”, to 56%, when only the two heaters are “on” and the writer is “off”. It can also be seen from Fig. 3 that the flying height prediction for the case that both the writer and the heaters are “on” (“Writer & DH ON”) does not equal the flying height calculated from the ABS with the thermal protrusion profile as the case “Writer + DH”. The difference at the write and read elements is 12% (0.4 nm) and 8% (0.2 nm), respectively.

3.2 The effect of distance between TFC heater 1 and the ABS

Figures 4 and 5 show the thermal protrusion and flying height profiles along the center line of the slider as the distance between TFC heater 1 and the ABS (i.e. D1) is increased from 12 to 28 μm. We observe that the change in the thermal protrusion and flying height at the write element is smaller than the change at the read element. This is because heater 1 is located near the read element and therefore the distance between heater 1 and the ABS is more sensitive to the thermal protrusion and flying height reduction at the reader than at the write element.

Figure 6 shows the flying height at the read/write element as a function of D1. We observe that with increasing D1 the flying height at the read element increases rapidly (from 4 to 6.3 nm, when the writer is “on”) while the flying height change at the write element is smaller than 0.2 nm. A similar trend occurs in the case that the write current is turned “off”. In addition, Fig. 6 shows that the flying height difference for the write current being “on” or “off” is smaller for the read element than for the write element, i.e. the write current has a smaller effect on the flying height change of the reader than of the writer.

Thermal actuation efficiency at the read element reduces from 61 to 35% as the distance between heater 1 and ABS increases from 12 to 30 μm. The effect of D1 on the thermal actuation efficiency at the write element is smaller than 7% as shown in Fig. 7.

3.3 The effect of distance between TFC heater 2 and the ABS

Figures 8 and 9 show the flying height and the thermal actuation efficiency at the read and write element as a function of D2. It can be seen that the flying height reduction and the thermal actuation efficiency at both the read and the write element decreases as D2 decreases. A similar trend for the effect of the write current on the flying height of the read/write element can be observed. In particular, the flying height difference for the case that the write current is “on” and
“off” is smaller for the read element than for the write element, i.e., the write current has a smaller effect on the flying height change at the reader than that at the writer.

Figure 10 shows the temperature increase $\Delta T$ at the reader as TFC heater 1 and heater 2 moving away from the ABS. The results are normalized for the reference case where both dual heaters and writer are “on”, and the distance between ABS to heater 1 and heater 2 are 12 and 23 $\mu$m, respectively. The temperature rise at the reader decreases as the heaters move away from the ABS. In addition, the distance between heater 1 and ABS, i.e. $D_1$, contributes more to the temperature variation at the reader than $D_2$.

3.4 The effect of the power ratio of dual TFC heaters

Figures 11 and 12 show the effect of power partitioning between heater 1 and heater 2 in a slider with dual TFC
heaters. The total power input $P_T$ was kept constant. The ratios investigated varied from 1:3 to 3:1. We observe that an increase in the power input of heater 1 (i.e. $P_1$) leads to an increase of the thermal protrusion at the reader. This causes a decrease in the flying height at the reader. A similar relationship was found between heater 2 and the writer.

Figure 13 compares the flying height profiles for different input power into the dual heaters, with the writer being “on” and “off”. In particular, Fig. 14 plots the flying height difference between the read element and the write element as the power ratio of heater 1 increases. It can be observed that for the particular TFC slider design under consideration ($D_1 = 12 \, \mu m$ and $D_2 = 23 \, \mu m$), partitioning of approximately 40% of the heat input for heater 1 achieves a high flying height reduction while keeping the flying height difference at the reader and writer approximately equal to the original design of the ABS without any thermal protrusion considered. When the writer is “on”, however, the power ratio of heater 1 should be increased to 55% to compensate for the effect of the write current. Thus, it is very important to carefully select the input power of the heaters to optimize the flying characteristics of TFC sliders during drive operations.

4 Conclusion

A TFC slider with two separate TFC heaters and two individual insulator elements was investigated for the two cases that the write current was either “on” or “off”. It was found that the write current has a smaller effect on the flying height change at the reader than at the writer. In order to reduce the flying height and improve the thermal actuation efficiency of the read/write element, both heater elements of a dual TFC slider must be positioned in close proximity to the ABS. For a given position of heater 1 and heater 2, the power ratio of the heaters must be carefully selected to achieve low flying height, high thermal efficiency, and reduced dependence of the write current on spacing changes at the read and write elements.

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