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PERFORMANCE OPTIMIZATION OF THERMAL NANO-ACTUATOR FOR FLY HEIGHT CONTROL IN DISK DRIVES

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ABSTRACT

Slider with thermal fly height control (TFC) uses a thermal heater to produce localized thermal protrusion and adjust the vertical position of the read/write head. This paper reports authors' efforts in exploring large protrusion stroke with minimal heater power input whilst preserving heater robustness in the TFC slider, with an optimized thermal nano-actuator design. Effects of both heater line width and line spacing on TFC slider performances are investigated. A novel 'Stream-River' heater design approach is proposed. Simulation results conclude that the "Stream-River" approach is of both high power-protrusion efficiency and high heater robustness.

INTRODUCTION

Increasing areal density in hard disk drive requires lower slider fly height (FH). The thermal nano-actuator and thermal fly height control (TFC) was introduced to slider design in recent years, aiming to achieve adjustable FH and ensure that FH is at the expected precise value. It uses a thermal heater to produce localized thermal protrusion and adjust the vertical position of the read/write head. One key performance parameter for such a thermal nano-actuator is the power-protrusion efficiency which is the ratio of protrusion stroke to the heater power used. The thermal actuator design is introduced by Meyer et al. in 1999 [1] and various efforts have been made to improve the power-protrusion efficiency [2,3]. Researchers also explored how to achieve higher FH change for the same amount of heater power input [2,4-6] and higher FH change for the same amount of protrusion[7].

Another important performance factor for the thermal nano-actuator is its robustness. Local heating will result in von Mises stress and the heater yields when its von Mises stress exceeds the yield strength. It is desirable to incur lower von Mises stress for the same amount of thermal protrusion stroke. Thus, the stress-stroke ratio is introduced as a heater reliability indicator. It is important to explore details of heater design and design strategy. However, few papers discuss the optimization of the thermal actuator design to achieve both high power-protrusion efficiency and lower stress-stroke ratio.

This paper reports the authors' effort in exploring high power-protrusion efficiency and strong heater reliability (low stress-stroke ratio). Effects of heater line width and line spacing on TFC slider performance are studied. A 'Stream-River' heater design approach is proposed; results suggest that it is capable of both achieving high power- protrusion efficiency and preserving heater reliability.

INVESTIGATION PLATFORM

Numerical analysis was conducted for the design performance evaluation and the exploration of optimized thermal nano-actuators. The modeling work is based on commercial software ANSYS. A 3-D finite element (FE) TFC slider model, as illustrated in Fig. 1a, is employed to first solve the heat transfer problem and obtain the temperature distribution in slider body. The same method is then used to calculate protrusion size of the slider model.

Fig. 1b illustrates the components of the TFC slider structure used in this modeling. They consist of a tantalum heater, NiFe shields, NiFe magnetic poles and copper write coil. The heater power input is fixed at 20.0mW for all simulations conducted in this work. The top edge of the heater is fixed at a position 5.00µm below the ABS surface. The main variables used in the simulation include heater line width and line spacing. Table 1 lists the major parameters used in this work.

Table 1: Major parameters for different heater designs in this work.

Heater Design	A	B	C	D	E
Heater Line Width(µm)	1.50	1.00	0.50	1.50	1.50
Heater Line Spacing(µm)	0.50	0.50	0.50	1.00	1.50
Heater Thickness (µm)	0.08	0.08	0.08	0.08	0.08

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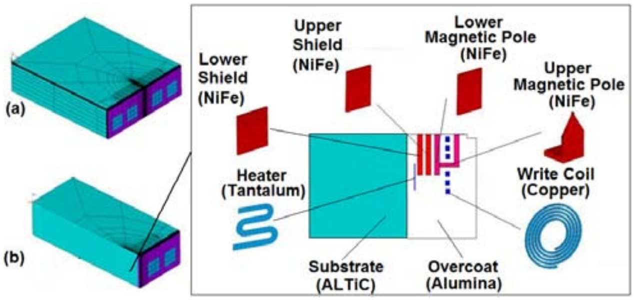

Fig. 1: (a) 3-D Finite Element Model of TFC slider. (b) Details of TFC slider components.

RESULTS AND DISCUSSION

Effect of Heater Line Width

Heater designs A, B and C, as illustrated in Fig. 2, are simulated. Results are summarized in Table 2. All the 3 designs are of uniform heater line width of 1.5µm, 1.0µm and 0.5µm, respectively.

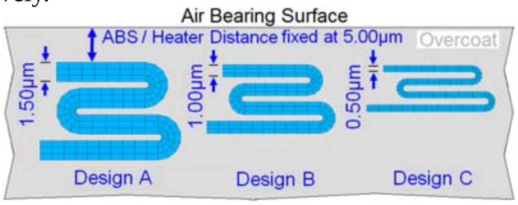

Fig. 2 Illustration of heater designs with same total length, heater line spacing but different heater line width (1.5 µm, 1.0 µm, 0.5 µm).

Table 2: Simulation results of heaters with different heater line width

Heater Design	A	B	C
Heater Line Width(µm)	1.50	1.00	0.50
Protrusion Size (nm)	6.79	7.25	7.81
Power-Protrusion Efficiency (nm/mW)	0.339	0.362	0.390
Von Mises Stress (MPa)	297	402	570
Stress-Stroke Ratio (MPa/nm)	43.8	55.5	73.0

As heater line width narrows from 1.5µm to 1.0µm and 0.5µm, the power-protrusion efficiency increases by 6.78% and 15.0%, respectively. This suggests that reducing line width increases power-protrusion efficiency. However, it can also be observed that the von Mises stress increases significantly as the line width reduces. In fact, the stress-stroke ratio increases from 43.8MPa/nm for 1.5µm line width to 55.5MPa and 73MPa for 1.0µm and 0.5µm line width respectively. Fig. 3 illustrates the temperature profile of the 3 cases. As heater line width narrows, maximum heater temperature increases. It can also be observed that the location of the maximum temperature area shifts towards the ABS surface. This is due to the fixed line length and the ABS/heater distance. Protrusion efficiency is enhanced as the maximum temperature in the heater body becomes higher and the overall heater body is closer to the free boundary at slider's ABS [7]. The maximum temperature increases with narrower heater line width as heating power is more concentrated to a smaller heater area for the narrower line width case. Heater with elevated temperature accumulates higher von Mises stress.

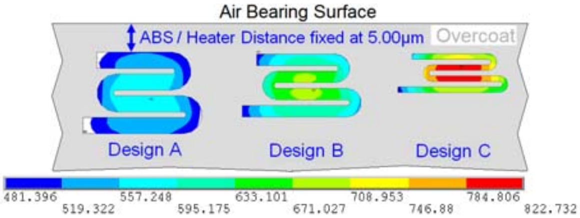

Fig. 3 Temperature distribution of heater designs A, B and C. Color Bar indicates temperature scale in Kelvin.

Effect of Heater Line Spacing

Heater designs of different uniform line spacing are investigated. Fig. 4 illustrates heater design A, D and E with uniform line spacing of 0.5µm, 1.0µm and 1.5µm respectively. Table 3 summarizes the simulation results.

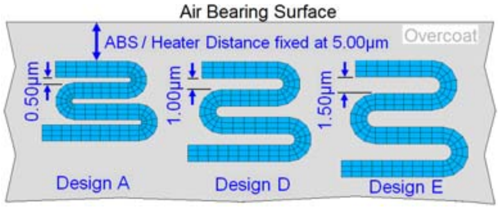

Fig. 4 Illustration of heater designs with same total length, heater line width but different heater line spacing (0.5 µm, 1.0 µm, 1.5 µm).

Table 3: Simulation results of heaters with different line spacing.

Heater Design	A	D	E
Heater Line Spacing(µm)	0.50	1.00	1.50
Protrusion Size (nm)	6.79	6.52	6.30
Power-Protrusion Efficiency (nm/mW)	0.339	0.326	0.315
Von Mises Stress(MPa)	297	255	223
Stress-Stroke Ratio (MPa/nm)	43.8	39.2	35.5

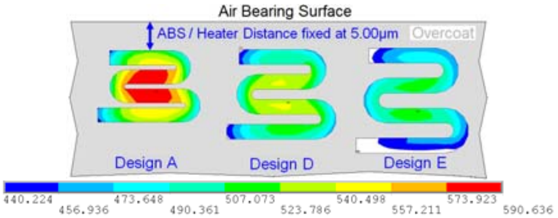

Fig. 5 Temperature distribution of heater design A, D and E. Color bar indicates temperature scale in Kelvin

The power-protrusion efficiency drops by 3.83% and 7.07%; when heater line spacing widens from 0.5µm to 1.0µm and 1.5 µm, respectively. On the other hand, the stress-stroke ratio reduces by 10.6% and 18.9% respectively. As illustrated in Fig. 5, heater maximum temperature decreases and shifts away from ABS surface when the line spacing widens. When maximum heater temperature shifts away from ABS, the drop in protrusion stroke decreases power-protrusion efficiency. The wider spread of heating power in larger heater relative to smaller ones causes a decline in its maximum temperature. Lower temperature heater accumulates less von Mises stress.

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Optimization -- ‘Stream-River’ Heater Design approach

Results from previous simulations unveil a conflict between achieving good power-protrusion efficiency and strong heater reliability. A ‘Stream-River’ heater design approach is proposed to overcome this obstacle.

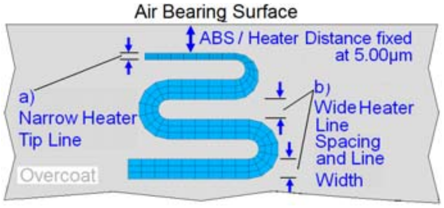

Fig. 6: A ‘Stream-River’ approach heater design consists of a) narrow heater tip line at top (towards ABS) b) fixed wider line width for the rest part of the heater and wider heater line spacing

The main features and underlying concept of ‘Stream-River’ heater approach is illustrated in Fig. 6. The approach includes the following two key points: (a) narrow heater tip line, to shift the maximum temperature area towards the ABS and boost power-protrusion efficiency, and (b) wide heater line spacing and line width, to maintain lower heater temperature gradient in the heater area which is essential to lower heater von Mises stress and thus strengthens its reliability --- smaller stress-stroke ratio. ‘Stream-River’ heater design F and G are simulated; Table 4 and 5 summarizes their simulation parameters and results respectively.

Table 4: Simulation parameters of ‘Stream-River’ heaters with different heater tip line width.

Heater Design	F	G
Heater Tip Line Width (µm)	0.50	1.38
Heater Line Width(µm)	1.50	1.50
Heater Line Spacing(µm)	1.50	1.50
Heater Thickness (µm)	0.08	0.08

Table 5: Simulation results of ‘Stream-River’ heaters with different heater tip line width.

Heater Design	F	G
Heater Tip Line Width (µm)	0.50	1.38
Protrusion Size (nm)	7.92	7.04
Power-Protrusion Efficiency (nm/mW)	0.396	0.352
Von Mises Stress (MPa)	432	208
Stress-Stroke Ratio (MPa/nm)	54.5	29.5

Comparing results of design F and C (Table 2), it is observed that design F achieves almost similar high power-protrusion efficiency as design C; yet its von Mises stress is 24.2% lower than design C. It can be observed from Fig. 7 that design F’s narrow tip line shifts the maximum temperature area of the heater towards the ABS surface and enhances power-protrusion efficiency. Design F’s wide line spacing and wide line width for the rest part of the heater reduce the von Mises stress.

Results of design G and E were compared in Table 5. Design G is able to maintain the same relatively low von Mises stress as design E and yet achieve 11.7% higher power-protrusion efficiency. Both design G and E share almost similar wide line width and spacing, which explain their affinity in low von Mises stress. Design G is of slightly narrower (1.38µm vs 1.50µm) tip line width comparing with Design E. However, such a slightly narrower tip line still enables a higher power-protrusion efficiency.

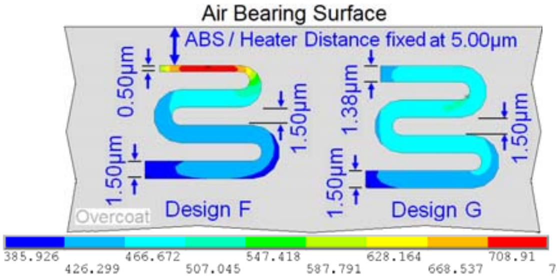

Fig. 7: Temperature distribution of heater design F and G. Color Bar indicates temperature scale in Kelvin.

CONCLUSION

The optimization of TFC heater design is investigated in this paper to achieve both high power-protrusion efficiency and preserve robustness of the thermal actuator. Narrowing heater line width increases power-protrusion efficiency also results in high von Mises stress. Widening the heater line spacing deceases power-protrusion efficiency yet enhances heater robustness. The conflict of achieving both desired TFC slider performances was solved with the proposed ‘Stream-River’ heater design approach.

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