Simulation of Piezoelectric Flying Height Control Slider Using Shear-Mode Deformation

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Abstract

The piezoelectric flying height control slider has recently been implemented in magnetic recording disk drives to reduce the flying height. This paper has examined the piezoelectric flying height control slider using shear-model deformation of piezoelectric transducer (PZT). A finite element model of the PZT slider using shear-model deformation has been built, and the electromechanical simulation and air-bearing simulation have been performed to investigate the effects of the shear-model deformation on the static flying attitude of the PZT slider. The results show that the flying height and pitch angle of the PZT slider can be significantly reduced with an increase in the drive voltage on the PZT sheet. However, beyond the drive voltage of 80 V for the proposed PZT slider, the reduction in the flying height of PZT slider is limited owing to the high air bearing stiffness at low flying height region. Furthermore, the PZT slider can be rotated and balanced at a negative pitch angle.

1. Introduction

The active-head slider technology has recently been implemented in magnetic recording disk drives to reduce the flying height at the read/write element. The two typical actuators to drive an active-head slider are thermal actuator and piezoelectric actuator.

Using a thermal actuator, the thermal flying height control (TFC) slider enables the control of the temperature distribution inside the slider, thereby resulting in a greater flying height reduction [1–7]. In a recent investigation, a thermal insulator was proposed to control the temperature distribution inside the slider, thereby resulting in a greater flying height reduction than that obtained with a TFC slider without insulators [8]. Moreover, the simulation results showed that two separate TFC heaters, each with an individual thermal insulator element, can further reduce the...
flying height at the read/write element, when compared with that of a single TFC heater [9]. Dual TFC heaters and thermal insulators can provide a flexible control of flying height and thermal response time [10]. However, the incorporation of thermal insulators and dual TFC heaters do not seem to cause an increase in the time required for establishing thermal equilibrium. In other words, the dynamic response of TFC slider is slower, and it is difficult for the TFC slider to catch up the dynamic variation caused by micro waviness and disk vibration.

Some active-head sliders with a piezoelectric actuator have already been proposed. A novel concept for an active-head slider was proposed earlier and was successful in experimentally controlling the head/disk spacing [11]; however, it was larger than the practical sliders. Subsequently, a series of slider designs with different PZT thin films were proposed [12–15]. Nevertheless, these PZT sliders are difficult for fabrication and their air-bearing stiffness becomes weak owing to their structure design. Recently, a shear-mode deformation of PZT sheet was used to enable dynamic flying height control [16]. The PZT sheet was deformed in the shear mode and the flying height of the magnetic head was changed when the voltage was applied between the lower and upper electrodes. The experiment results showed that its response time is significantly faster than that of a conventional TFC slider.

In this paper, we have examined the piezoelectric flying height control slider using shear-model deformation of piezoelectric transducer (PZT). We have built a finite element model of a piezoelectric flying height control slider using shear-model deformation. By applying a drive voltage, we have simulated the shear-mode deformation of PZT slider and the corresponding flying attitude of the slider.

2. Finite Element Model

A schematic model of a PZT slider is shown in Fig. 1. A three-pad conventional slider of a standard "Pico-slider" size (1.25×1×0.3 mm³) was chosen. A PZT sheet (NEC/Tokin N-21) [18] was designed between the substrate and basecoat in the conventional slider, and its distance to the trailing edge of slider \( D \) was 42.8 µm. The thickness of the PZT sheet \( L \) was chosen to be 200 µm, and its width and height were designed as the same as those of the slider.

When applying a drive voltage on the PZT sheet, the PZT sheet was found to have a shear-mode deformation \( \Delta x \) [17–18] towards the disk, which resulted in the change of flying attitude of the slider.

\[
\Delta x = d_{15}^* V
\]

where \( V \) is the drive voltage and \( d_{15}^* \) is the piezoelectric charge constant of the shear-mode deformation. In the simulation, we chose substrate side as the upper electrode and basecoat side as the lower electrode.

Figure 2 shows the cross-sectional view of the finite element model of the PZT slider using the commercial software ANSYS. It comprised the head elements of pole tips, shields, writer coil, and PZT sheet. The ANSYS element types of SOLID98 and SOLID226 were chosen for the slider and PZT sheet, respectively. Tables 1 and 2 list the material properties of PZT slider components used in the finite element simulation [3][5][18].
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Fig. 2 Finite element model of PZT slider (half slider plotted).

Table 1. Material properties of the slider used in ANSYS.

| Materials                  | Young’s modulus (GPa) | Poisson’s ratio | Density (kg/m³) |
|----------------------------|-----------------------|-----------------|-----------------|
| Al₂O₃TiC (Substrate)       | 390                   | 0.22            | 2200            |
| Al₂O₃ (Basecoat)           | 138                   | 0.25            | 2200            |
| NiFe (pole, shield)        | 200                   | 0.3             | 700             |
| Cu (writer coil)           | 130                   | 0.34            | 8960            |
| PZT (NEC Tokin N-21)       | Y₁₁ 61                | 0.34            | 7820            |

Table 2. Electrical properties of PZT sheet used in ANSYS.

| PZT            | Piezoelectric charge constant (e-12 m/V) | Piezoelectric voltage constant (e-3 V·m/N) | Dielectric constants |
|----------------|------------------------------------------|--------------------------------------------|----------------------|
| NEC Tokin N-21 | d₃₁ -198                                  | g₃₁ -12.1                                  | ε₃₁/ε₀ 1800          |
|                | d₃₃ 417                                   | g₃₃ 25.4                                   |                      |
|                | d₃₅ 711                                   | g₅₅ 41.0                                   | ε₃₅/ε₀ 2000          |

3. Simulation Results

We first perform the electromechanical simulation of PZT slider under a given drive voltage to obtain the piezoelectric shear-mode deformation of the slider body. The deformed air-bearing surface of the PZT slider can be used to calculate the steady-state flying characteristics of the PZT slider using air-bearing simulation [19]. Subsequently, the effects of the drive voltage on the static flying attitude of the slider were investigated.
3.1. Electromechanical simulation of PZT slider

Figure 3 shows the finite element simulation results of the slider deformation under a drive voltage of 80 V. It can be seen that the shear-mode deformation of the slider body is gradually increased from the substrate side to basecoat side. Furthermore, it can be observed that the deformation of the trailing part is maximum at 72.9 nm towards the disk.

Figure 4 shows the shear-mode deformation profile of the PZT slider under the drive voltage of 80 V. The profile is linear along the thickness direction of the PZT sheet. Moreover, from the trailing edge of the slider to the location of the PZT sheet (42.8 µm to the trailing edge), the deformation is constant with a value of 72.9 nm.
3.2. Static air bearing simulation of PZT slider under the voltage of 80 V

Figure 5 compares the air-bearing pressure distribution on the air-bearing surfaces (ABS) of the conventional slider and PZT slider. The maximum pressure is $1.65 \times 10^6$ Pa on the ABS of the conventional slider, and is located at the trailing edge of the rear pad. On the ABS of the PZT slider, the distribution of the peak pressure obviously has a wide shape pattern, and the maximum pressure is increased to $3.74 \times 10^6$ Pa, which is about 2.3 times greater than that of the conventional slider. This is because the trailing part of the slider is vertically shifted towards the disk owing to the shear-mode deformation of the PZT sheet. Correspondingly, the air-bearing pressure profiles have been compared in Fig. 6. It can be observed that the PZT slider has a narrower but sharper pattern of pressure profile, when compared with the conventional slider.

Figure 7 compares the flying height profiles of the conventional slider and PZT slider. The lowest flying height of the conventional slider is 8.40 nm and the pitch angle is 97.66 $\mu$rad in the steady state. By applying a voltage of 80 V on the PZT sheet of the PZT slider, the lowest flying height is reduced to 4.24 nm and the pitch angle is significantly reduced from 97.66 $\mu$rad to 5.29 $\mu$rad.
3.3. Shear-mode deformation and variation of flying attitude at different drive voltages

Figure 8 shows the shear-mode deformation profiles of PZT slider under the voltages from 30 to 120 V. It can be seen that all deformation profiles show a similar pattern. Furthermore, the maximum deformation is observed to be
proportional to the drive voltage, as indicated by (1).

With an increase in the drive voltage, the pattern of the air-bearing pressure on the trailing part of the slider becomes narrower and the peak value of the air-bearing pressure is gradually increased (Fig. 9). It can be found that the pressure at the leading side of the trailing part is significantly increased with the increase in the drive voltage. Especially, in the cases of 100 and 120 V, a pressure peak appears at the leading side of the trailing part of the slider, as well as at the lowest flying height (shown in Fig. 10).

Figure 10 shows that when the drive voltage is beyond 80 V, the flying height of the PZT slider is not significantly reduced like that in the cases of 30, 50, and 80 V. The slider is rotated to fly at a reduced pitch angle or even at a negative pitch angle, rather than a further reduced flying height. For example, in the cases of drive voltages of 100 and 120 V, the flying height at the leading side of the trailing part of the slider is smaller than that at the trailing side. This indicates that the slider has a rotation to be balanced at a negative pitch angle. The results of negative pitch angles at the drive voltages of 100 and 120 V, shown in Fig. 11, confirm this point. This may be owing to the fact that the very strong air-bearing stiffness at low flying height resists the trailing part of the slider further dropping-down towards disk.

Figure 11 also indicates that the PZT slider is gradually rotated from a positive to a negative pitch angle with an increase in the drive voltage on the PZT sheet. This phenomenon can be explained in the view of the balance of the air-bearing force on the slider, as shown in Fig. 12. For a steady flying of the slider, the forces acting on the slider should be in the balance state, that is,

\[ F_{\text{suspension}} = F_{\text{left}} + F_{\text{right}} \]

\[ F_{\text{left}} > F_{\text{right}} : \text{positive pitch angle} \]

\[ F_{\text{left}} < F_{\text{right}} : \text{negative pitch angle} \]  

At a high drive voltage, the shear-mode deformation of the trailing part of the slider is large and uniquely approached to the disk. The air-bearing force on the trailing part \( F_{\text{trailing}} \) takes a primary role to balance the push-down force from the suspension \( F_{\text{suspension}} \). On the other hand, the rest of the parts of the slider (side pads, leading pads, etc.) move away to the disk owing to a large shear-mode deformation of the slider, that is, \( F_{\text{leading}} \) is gradually reduced. The variation of \( F_{\text{trailing}} \) and \( F_{\text{leading}} \) will cause the change in the weight factor of \( F_{\text{left}} \) and \( F_{\text{right}} \), which determine the pitch angle of the flying slider. When the drive voltage reaches a certain value (about 80 V for present design), the slider is rotated counterclockwise and balanced at a small negative pitch angle (cases of 100 V and 120 V) owing to \( F_{\text{left}} < F_{\text{right}} \).

The reason for the successfully flying of the slider with a small negative pitch angle should be the fact that the large and wide shear-mode deformation of the trailing part of the slider can still hold sufficient air-bearing force, in association with the weak supporting from the rest of the parts of the slider (side pads, leading pads, etc.). However, this kind of negative pitch angle flying is not applicable to the present hard disk drive.

Hence, a high drive voltage may cause the rotation of the PZT slider and slider flying at small/negative pitch angle. A parametric study (such as the thickness of PZT sheet \( L \), the distance of PZT sheet to the trailing edge of slider \( D \), the ABS design, etc.) needs to be performed in future works to achieve a robust head-disk interface and optimize the power efficient, that is, achieving a large flying height reduction at a low power cost.
Fig. 8. Comparison of deformation profiles under different drive voltages.

Fig. 9. Comparison of air-bearing pressure profiles under different drive voltages.

Fig. 10. Comparison of flying height profiles under different drive voltages.
4. Conclusion

This paper examined the piezoelectric flying height control slider using shear-model deformation. A finite element model of a PZT slider using shear-model deformation was built. The electromechanical simulation and air-bearing simulation were performed to investigate the effects of the shear-model deformation on the static flying attitude of the PZT slider.

The results show that the flying height and pitch angle of the PZT slider are significantly reduced with the increase in the drive voltage on the PZT sheet. However, beyond the drive voltage of 80 V for the proposed PZT slider, the reduction in the flying height of the PZT slider was found to be limited owing to the high air-bearing stiffness at low flying height region. Furthermore, the PZT slider can be rotated and balanced at a negative pitch angle, and an optimization work is necessary to achieve a robust head-disk interface and high power efficiency.

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