THERMAL MODEL OF ULTRA-THIN FILM HEAD SLIDERS IN MAGNETIC STORAGE SYSTEM

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Abstract

This paper investigates the thermal effect on the characteristic of the magnetic head slider in magnetic storage systems. The heat generates due to read/write device in the magnetic head slider and viscous dissipation which transfers from the air bearing to the magnetic head slider. Continuity equation, Navier Stoke's equation and energy equation are formulated and calculated numerically to obtain flying height, air bearing temperature distribution and heat transfer between the air bearing and the magnetic head slider. The spacing between the slider and the disk was also simulated with the variation of head parameters.

The results show the air film at trailing edge of the head slider was significant increased due to the electrical current activated during read/write operation.

1. Introduction

Thermal effects in slider/disk air bearing have previously investigated, Tian et al (1997)[1], Zhang and Bogy (1999)[2] reported temperature variation phenomena in the air bearing. A phenomena called thermal asperities due to flash temperature that rise when a slider with the MR transducer flies close to a disk without contact. Then Zhang and Bogy, they introduced a thermal model using discontinuous boundary conditions in a thin slider/disk air bearing and solve it numerically. They found that heat flux occurs by heat conduction mainly which transfers heat from the slider to the air bearing when the slider has higher surface temperature than the disk and viscous dissipation.

This paper introduces theoretical investigations in heat transfer between the slider and the air bearing from Reynolds equation, Navier Stokes equation and energy equation using discontinuous boundary condition[2]. A computer program was implemented to obtain temperature distribution and heat flux distribution in tapered-flat type slider, truncated cycloidal-flat type slider and exponential-flat type slider.

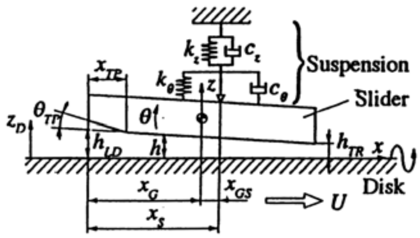

Fig . 1 Magnetic head slider.

2. Theoretical analysis

2.1 Reynolds equation

At present, high performance magnetic head/disk requires only sub-micro flying height. Fig.1 shows magnetic head slider system for this study. Reynolds equation with the effect of molecular slip can be expressed as

$$\frac{\partial}{\partial x}\left[ph^3\left(1+\frac{6a_0KnP_0h_m}{ph}\right)\frac{\partial p}{\partial x}\right]+\frac{\partial}{\partial y}\left[ph^3\left(1+\frac{6a_0KnP_0h_m}{ph}\right)\frac{\partial p}{\partial y}\right]$$
$$=6\eta_a\frac{\partial(Uph)}{\partial x} \tag{1}$$

which h_m is reference air film thickness p is air pressure P_0 is ambient air pressure, η_a is air viscosity at ambient air pressure, a_0 is surface factor.

2.2 Navier Stokes equations

The simplification of Navier Stokes equations for bearing has been performed by many researchers[2], can be expressed as

$$\frac{\partial p}{\partial x} = \mu \frac{\partial^2 u}{\partial z^2} \quad (2a)$$

$$\frac{\partial p}{\partial y} = \mu \frac{\partial^2 v}{\partial z^2} \quad (2b)$$

$$\frac{\partial p}{\partial z} = 0 \quad (2c)$$

where u, v are velocities in x and y directions. p is the pressure and μ is the viscosity of air. For simplification, we assume μ is uniform in the air bearing. The velocity component w in the z direction is approximated to be zero. Clearly, the pressure p is constant across the thickness of the air bearing.

2.3 Energy equation

Since the magnitudes $|\partial/\partial x| \approx |\partial/\partial y| << |\partial/\partial z|$ and the velocity of air in z direction is approximately zero in a lubrication problem. We neglect the small terms and rewrite the energy equation as

$$k\frac{\partial^2 T}{\partial z^2} + \mu\left(\frac{\partial u}{\partial z}\right)^2 + \mu\left(\frac{\partial v}{\partial z}\right)^2 = 0 \quad (3)$$

Normally, the viscous dissipation term is smaller in magnitude than the conduction term in equation (3) but when temperature difference between slider and disk surface is close or equal to zero " warming effect " of viscous dissipation can not be neglected. Therefore, we interest this term in equation (3) for analysis.

2.4 Boundary condition

We assume disk velocity U does not equal zero in x direction and velocity V equals zero in y direction that is the case which slider flying at mid-radius of the disk. For temperature, considering that the disk is much larger than the air bearing and rotating with high speed. We assume that the disk has constant speed and uniform temperature. Introducing slip condition for the velocity and jump condition for temperature at the boundaries of the air bearing [2,3]. The boundary conditions for velocity and temperature can be written as

$$u(0) = U + \frac{2-\sigma_M}{\sigma_M}\lambda \left.\frac{\partial u}{\partial z}\right|_{z=0} \quad (4a)$$

$$u(h) = -\frac{2-\sigma_M}{\sigma_M}\lambda \left.\frac{\partial u}{\partial z}\right|_{z=h} \quad (4b)$$

$$v(0) = -\frac{2-\sigma_M}{\sigma_M}\lambda \left.\frac{\partial v}{\partial z}\right|_{z=0} \quad (4c)$$

$$v(h) = -\frac{2-\sigma_M}{\sigma_M}\lambda \left.\frac{\partial v}{\partial z}\right|_{z=h} \quad (4d)$$

$$T(0) = T_d + 2\frac{2-\sigma_T}{\sigma_T}\frac{\gamma}{\gamma+1}\frac{\lambda}{\mathrm{Pr}}\left.\frac{\partial T}{\partial z}\right|_{z=0} \quad (4e)$$

$$T(h) = T_s + 2\frac{2-\sigma_T}{\sigma_T}\frac{\gamma}{\gamma+1}\frac{\lambda}{\mathrm{Pr}}\left.\frac{\partial T}{\partial z}\right|_{z=h} \quad (4f)$$

where σ_M is momentum accommodation coefficient and σ_T is thermal accommodation coefficient γ is ratio of C_p to C_v which are specific heats at constant pressure and constant volume respectively. T_s and T_d are the slider surface temperature and the disk surface temperature respectively. For convenience, we write $a = (2-\sigma_M)/\sigma_M$ and $b = 2(2-\sigma_T)\gamma/\sigma_T(\gamma+1)\mathrm{Pr}$ in the following analysis.

2.5 Air film thickness

The air film thickness for taper-flat type slider can be written as

$$h = h_{TR} + (L - L_{TP})\tan\theta + (L_{TP} - x)\tan\theta_{TP} \quad ;0 \le x \le L_{TP} \quad (5a)$$

$$h = h_{TR} + (L - x)\tan\theta \quad ;L_{TP} \le x \le L \quad (5b)$$

3. Heat transfer in air bearing

To obtain heat transfer in the air bearing, we need to know temperature distribution by solving Navier Stoke equation and energy equation. Navier Stoke equation and energy equation with constant property approximation can be solved separately.

3.1 Velocity distribution

Velocity distribution can be obtained by integrating Navier Stoke equation (reduced form) (2a)-(2b) using boundary condition (4a)-(4d). With straight forward procedure, the results are as follow

$$u = -\frac{1}{2\mu}\frac{\partial p}{\partial x}\left(a\lambda h + hz - z^2\right) + U\left(1 - \frac{z + a\lambda}{h + 2a\lambda}\right) \quad (6a)$$

$$v = -\frac{1}{2\mu}\frac{\partial p}{\partial y}\left(a\lambda h + hz - z^2\right) \quad (6b)$$

3.2 Temperature distribution

We fill velocity result (6a) and (6b) into energy equation (3) then integrate to obtain temperature distribution in non-dimensional form as

$$
\begin{aligned}
(T_0)T^* = T_d &- \frac{1}{k}\left\{\frac{1}{12\mu}\left[\frac{P_0^2}{L^2}\left(\frac{\partial p^*}{\partial x^*}\right)^2+\frac{P_0^2}{B^2}\left(\frac{\partial p^*}{\partial y^*}\right)^2\right]h^4\left(z^*\right)^4\right.\\
&-\frac{1}{3}\left\{\frac{h}{2\mu}\left[\frac{P_0^2}{L^2}\left(\frac{\partial p^*}{\partial x^*}\right)^2+\frac{P_0^2}{B^2}\left(\frac{\partial p^*}{\partial y^*}\right)^2\right]+\frac{U}{(h+2a\lambda)}\frac{P_0}{L}\left(\frac{\partial p^*}{\partial x^*}\right)\right\}h^3\left(z^*\right)^3\\
&\left.+\frac{\mu}{2}\left\{\left(\frac{h}{2\mu}\frac{P_0}{L}\left(\frac{\partial p^*}{\partial x^*}\right)+\frac{U}{(h+2a\lambda)}\right)^2+\frac{h^2}{4\mu^2}\frac{P_0^2}{B^2}\left(\frac{\partial p^*}{\partial y^*}\right)^2\right\}h^2\left(z^*\right)^2\right\}\\
&+\left\{\frac{(T_s-T_d)}{(h+2b\lambda)}+\frac{1}{k}\left\{\frac{1}{24\mu}h^3\left[\frac{P_0^2}{L^2}\left(\frac{\partial p^*}{\partial x^*}\right)^2+\frac{P_0^2}{B^2}\left(\frac{\partial p^*}{\partial y^*}\right)^2\right]+\frac{\mu U^2 h}{2(h+2a\lambda)^2}\right.\right.\\
&\left.\left.+\frac{Uh^3}{6(h+2a\lambda)(h+2b\lambda)}\frac{P_0}{L}\frac{\partial p^*}{\partial x^*}\right\}\right\}\left(hz^*+b\lambda\right) \qquad (7)
\end{aligned}
$$

Similarly, equation of temperature consists both Poiseulle flow and Couette flow and the term are combined.

3.3 Heat transfer

From Fourier's law $q=-k\partial T/\partial z$ at $z=h$ and temperature distribution in equation (7), the heat flux distribution can be written in non-dimensional form as

$$
\begin{aligned}
\frac{qh}{\mu U^2} = &-\frac{T_s-T_d}{\left(\frac{\gamma-1}{2}\right)\Pr M^2 T_0\left(1+2b\frac{\lambda}{h}\right)}+\frac{1}{2\left(1+2a\frac{\lambda}{h}\right)^2}+\frac{1}{24}\mathrm{Re}^2\left(\frac{h}{L}\right)^2\left(\frac{P_0}{\rho U^2}\right)^2\left(\frac{\partial p^*}{\partial x^*}\right)^2\\
&+\frac{1}{24}\mathrm{Re}^2\left(\frac{h}{B}\right)^2\left(\frac{P_0}{\rho U^2}\right)^2\left(\frac{\partial p^*}{\partial y^*}\right)^2-\frac{1}{6}\mathrm{Re}\frac{h}{L}\frac{P_0}{\rho U^2}\frac{1}{\left(1+2b\frac{\lambda}{h}\right)\left(1+2a\frac{\lambda}{h}\right)}\frac{\partial p^*}{\partial x^*} \qquad (8)
\end{aligned}
$$

4. Simulation results

The simulation of heat transfer in the air bearing sliders was done at disk running with linear velocity at 20 m/s. Heat is generated in the air film between the head slider and the disk due to viscous dissipation. Temperature profile in the air bearing of taper-flat was calculated as shown in Fig.2. The peak temperature occurred near leading edge of the sliders. Heat flux distribution in the air bearing of tapered-flat slider is shown in Fig.3. The maximum heat flux also occurred near the leading edge of the sliders. The maximum temperature and maximum heat flux are obtained in the tapered-flat slider without electrical activated during read/write operation. The static characteristic of magnetic head were investigated included the effect of electrical activated during read/write operation; 8 mA, 13 mA, 18 mA, respectively.

The spacing between the head slider and the disk were simulated with the variation of slider rail width, taper length, taper angle, suspension position and suspension preload as shown Fig.4, Fig.5, Fig.6, Fig.7 and Fig.8 respectively. The results show that air film thickness at trailing edge was significantly increased due to the electrical activated at trailing edge of the head slider during read/write operation.

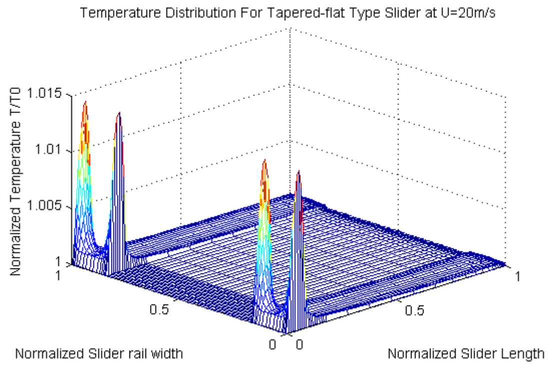

Fig. 2 Temperature profile in air bearing of tapered-flat type slider.

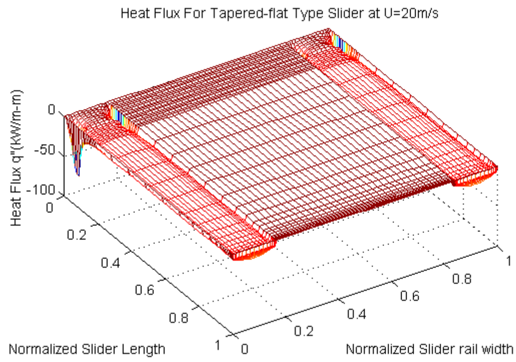

Fig. 3 Heat flux between slider and air bearing of tapered-flat type slider $(T_s - T_d = 0\,K)$.

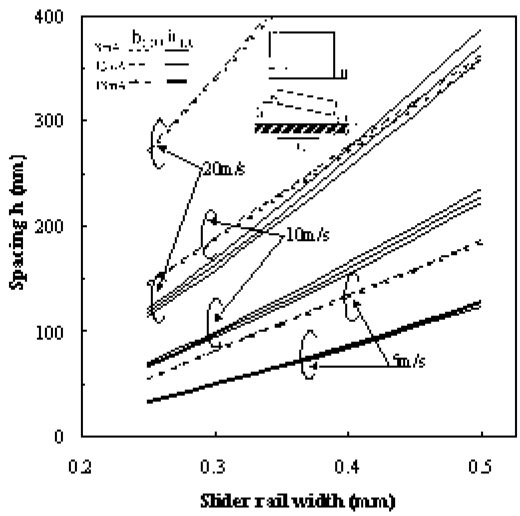

Fig.4 Spacing between the head slider and rigid disk with varying slider rail width.

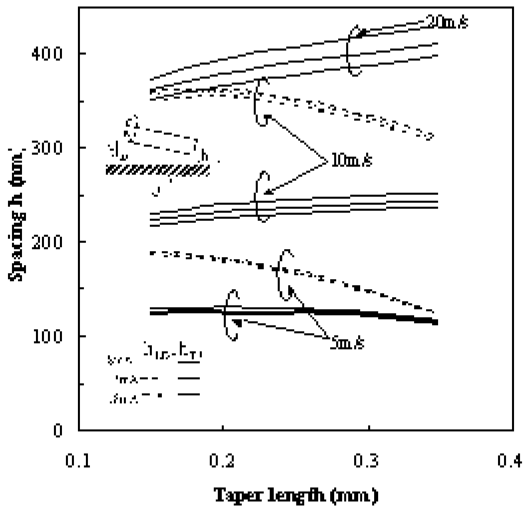

Fig.5 Spacing between the head slider and rigid disk with varying taper length.

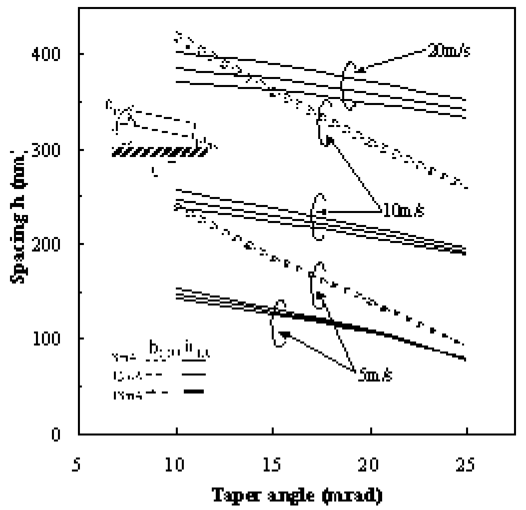

Fig.6 Spacing between the head slider and rigid disk with varying taper angle.

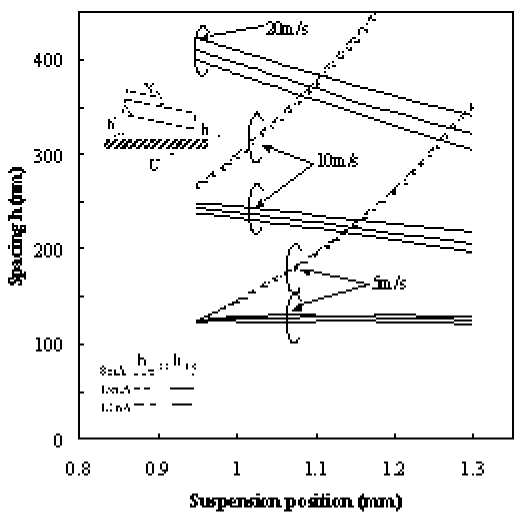

Fig.7 Spacing between the head slider and rigid disk with varying suspension position.

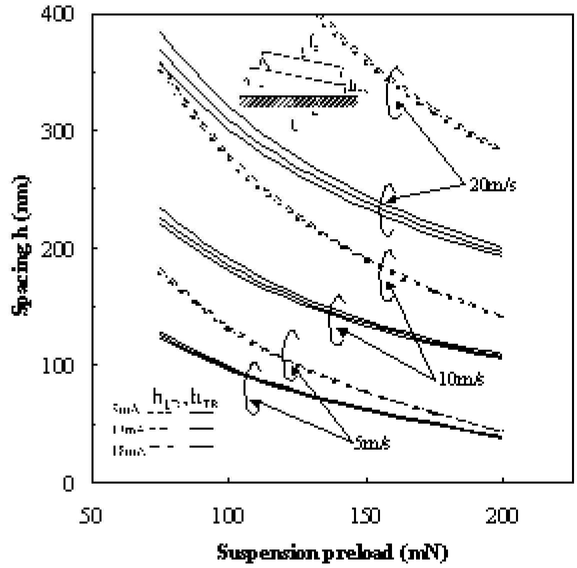

Fig.8 Spacing between the head slider and rigid disk with varying suspension preload.

5. Conclusions

In this study, the following conclusion are

1.Navier Stoke equation and energy equation are solved separately to obtain temperature distribution in the air bearings. Maximum temperature occurs near leading edge along the taper length of the head sliders.

2.From Fourier's law, heat flux can be calculated and the maximum heat flux occurs near leading edge along the taper length of the head sliders.

3.The spacing between the head slider and rigid disk was increased significantly especially at trailing edge of the head slider.

6. References

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7. Nomenclature

h air bearing space

h_{LD} air bearing space at leading edge

h_{TR} air bearing space at trailing edge

k thermal conductivity of the air

Kn Knudsen number

B width of the slider

L length of the slider

L_{TP} Taper length of the slider

M Mach number

p^* non-dimensional air bearing pressure $p^* = p/P_0$

Pr Prandtl number

q heat flux between the slider surface and the air bearing

R gas constant

Re Reynolds number

T_0 ambient air temperature

ΔT_0 temperature difference between the slider and disk surface

T^* non-dimensional temperature $T^* = T/T_0$

u^*, v^*, w^* non-dimensional velocity components $u^* = u/U, v^* = v/U, w^* = w/U$

x^*, y^*, z^* non-dimensional coordinates in the air bearing $x^* = x/L, y^* = y/L, z^* = z/h$

α thermal diffusivity of the air

λ mean free path of the air

ν dynamic viscosity of the air