Transient Response of The Optimal Taper-Flat Head Slider in Magnetic Storage Devices

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Abstract: This paper presents a method to predict the transient characteristic of the air lubricated slider head in a hard disk drive by using optimization technique. The time dependent modified Reynolds equation based on the molecular slip flow approximation equations was used to describe the fluid flow within the air bearing and the implicit finite difference scheme is applied to calculate the pressure distribution under the slider head. The exhaustive search combined with the Broyden-Fletcher-Goldfarb-Shanno method were employed to obtain optimum design variables which are taper angle, rail width and taper length in order to keep the forces and moments acting on the slider head in dynamic equilibrium. The results show that the optimal head slider of the magnetic head has good stability characteristic that can reach the steady state within 0.5 microsecond.

Keywords: Modified Reynolds equation, Equation of motion, Taper-Flat head slider, Molecular slip flow, Exhaustive search method, Broyden-Fletcher-Goldfarb-Shanno method

1. INTRODUCTION

The most critical factor to determine the performance of magnetic disk drives is the head/disk interface at which the flying magnetic head is to keep stable between head slider and disk surfaces under the static and dynamic operating conditions. There are many research works on optimum design of magnetic head sliders: O’Hara et. al. and Lu et. al. determined the optimum geometries of a subambient pressure shaped rail in magnetic head slider in 1996. Bogy et. al. obtained the optimal geometries with included the amplitude sensitivity as an objective function in 1998. In 2000, Hashimoto and Hattori obtained the optimum magnetic head slider using the combination of direct search method and the successive quadratic programming technique. The objective of this paper is to propose an efficient method to predict the static and dynamic flying characteristic of the optimal self acting air-bearing sliders in magnetic disk drives by using an optimization technique.

2. GOVERNING EQUATIONS

The schematic diagram of the magnetic slider head to be considered is shown in Fig.1. A rectangular coordinate system (X,Y) with the origin placed at the corner of the inner and leading edges and with the X and Y axes pointed in the slider’s length and width directions respectively. The slider was assumed to have two degree of freedom motion, translation perpendicular to the disk surface and rotation around the transverse axis. The generalized time dependent Reynolds equation for analyzing the air film pressure between the slider head and disk surfaces can be expressed as (1):

\[
\frac{\partial}{\partial X} \left( Q \frac{\partial P}{\partial X} \right) + R^2 \frac{\partial}{\partial Y} \left( Q \frac{\partial P}{\partial Y} \right) - \Lambda \frac{\partial}{\partial X} \left( \frac{\partial P}{\partial X} \right) - \sigma \frac{\partial (PH)}{\partial T} = 0
\]

where

\[
Q(P,H) = \phi(P,H)PH^3
\]

\[
\phi(P,H) = a_0 + a_1 \left( \frac{Kn}{PH} \right) + a_2 \left( \frac{Kn}{PH} \right)^2 + a_3 \left( \frac{Kn}{PH} \right)^3
\]

The boundary conditions are give as:

\[
P(0,Y,T) = P(X,Y,T) = P(X,-\frac{1}{2}T) = P(X,-\frac{1}{2}T) = P_a
\]

The slider head motion has two degree of freedom in this analysis and can be written as:

\[
M_\perp \dot{Z} + F_\perp = 2 \int_0^{1/2} \int_{-1/20}^{1/2} (P - P_a) dX dY
\]

\[
I_\theta \ddot{\theta} + M_\theta = 2 \int_0^{1/2} \int_{-1/20}^{1/2} (P - P_a) dX dY
\]

Equation (1), (5) and (6) can be solved numerically to obtain dynamic response of slider head.

3. OPTIMIZATION TECHNIQUE

The optimization problem for the solution of air bearing can be formulated using objective function as:

3.1 The objective function is to minimize static force and moment on the air bearing

\[
Y_1 = R_1^2 + R_2^2
\]

where

\[
R_1 = M_\perp Z + F_\perp - 2 \int_0^{1/2} \int_{-1/20}^{1/2} (P - P_a) dX dY
\]

\[
R_2 = I_\theta \ddot{\theta} + M_\theta - 2 \int_0^{1/2} \int_{-1/20}^{1/2} (P - P_a) dX dY
\]

3.2 The objective function is to minimize time to reach steady state condition

\[
\text{Min } T_{OL} = \frac{1}{T_p}
\]

\[
T_p = \frac{R_3}{R_4}
\]

\[
I_\theta = \frac{R_3}{R_4}
\]

\[
\text{Min } T_{OL} = \frac{1}{T_p} = \frac{R_3}{R_4}
\]

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3.3 The objective function is to minimize both static force and transient time in dynamic condition

\[
\text{Min} Y_3 = (W_1 \times FX_S) + (W_2 \times FX_D)
\]  
(14)

\[
FX_S = R_2^2 + R_2^2
\]  
(15)

\[
FX_D = R_3 + R_4 + R_5
\]  
(16)

The constraints are

\[
B^L \leq B \leq B^U
\]  
(17)

\[
\theta^U_{TP} \leq \theta_{TP} \leq \theta^L_{TP}
\]  
(18)

\[
L^L_{TP} \leq L_{TP} \leq L^U_{TP}
\]  
(19)

In this study, the static characteristic of the optimum taper-flat slider head was compared with the IBM 3380 taper-flat slider head as shown in Fig.5, Fig.6, Fig.7, Fig.8 and Fig.9 respectively. In Fig.5 shows the air film pressure distribution along X axis at y = B/2 of the optimum taper flat slider and compare with the IBM 3380 slider head. Fig.6 shows the pressure distribution along X and Y axes of the optimum taper flat slider. The spacing at leading and trailing edges are increase with the increase in disk speed as shown in Fig.7. The spacing at leading and trailing edges are changed slightly as the increase in suspension position and suspension preload as shown in Fig.8 and Fig.9 respectively.

For the simulation of dynamic characteristic of the optimum taper flat slider head was also compared with the IBM 3380 taper flat slider head as shown in Fig.10, Fig.11, Fig.12, Fig.13, Fig.14 and Fig.15. The dynamic response of the slider head under input bump with the bump height \( h = 0.1 \mu \text{m} \) and bump width \( w = 0.254 \text{cm} \) at various disk speed \( U = 15, 20 \) and \( 25 \text{ m/s} \). The response time are approximately 0.3 msec. in transient state. After \( t \geq 0.3 \text{ msec.} \) the flying slider head becomes steady state. Figure 16 shows the spacing between the head slider and rigid disk increase with the increase in disk velocity. The size of slider for OPT3 is \( B = 0.75 \text{ mm.} \) and \( \theta_{TP} = 11.31 \text{ mrad} \). Give the best static characteristic of taper-flat head slider for magnetic storage system.

5. CONCLUSION

The flying characteristics of the optimal taper flat self-acting air bearing slider are simulated and can be concluded as:

1) The optimal taper flat slider for minimize static force and moment on the air bearing give slightly larger spacing at trailing edge than the spacing for IBM 3380
2) The optimal taper flat slider has good dynamic characteristic that it can reach steady state with in 0.5 \( \mu \text{s.} \)
3) The best static characteristic head slider was obtained using both static and dynamic conditions in the objective function.
Fig.3 Contour curve of objective function and taper angle.

Fig.4 Contour curve of objective function and taper length.

Fig.5 Air film distribution along the slider length.

Fig.6 Air film pressure distribution for optimal slider head.

Fig.7 Variation of spacing with disk speed.

Fig.8 Variation of spacing with suspension position.
Fig. 9 Variation of spacing with suspension preload.

Fig. 10 Transient response of slider spacing for optimal slider head.

Fig. 11 Transient response of center of gravity for optimal slider head.

Fig. 12 Transient response of pitch angle for optimal slider head.

Fig. 13 Transient response of slider spacing for IBM 3380.

Fig. 14 Transient response of center of gravity for IBM 3380.
6. NOMENCLATURE

$B =$ slider rail width

$F_0 =$ normalized suspension pre load ($f_0/p\alpha L$)

$F_XD =$ Objective function for dynamic condition

$FXS =$ Objective function for static condition

$h_a =$ minimum allowable spacing

$h_{LD} =$ leading edge spacing

$h_{TR} =$ trailing edge spacing

$H =$ normalized spacing ($h/ha$)

$I_0 =$ normalized slider moment of inertia about the pitch axis

$(ih_0 \omega_0^2/p_\alpha L^2B)$

$Kn =$ Knudsen number ($\lambda/ha$)

$L =$ slider length

$L_{TP} =$ taper length

$M_Z =$ normalized slider mass ($m_h \omega_0^2/\rho_\alpha L^2B$)

$P =$ normalized pressure ($p/p\alpha$)

$P_a =$ ambient pressure

$T =$ normalized time ($\omega_0 t$)

$T_S =$ Time to reach steady state

$TOLT =$ Total time for the slider to move

$U =$ velocity of disk ($\omega_0 \alpha$)

$W_1 =$ Weight factor for static condition

$W_2 =$ Weight factor for dynamic condition

$X_{G0} =$ normalized location of the center of gravity ($x_{G0}/L$)

$X_{GS} =$ normalized distance between the center of gravity and support position ($x_{GS}/L$)

$X_S =$ normalized location of the support position ($x_S/L$)

$Z_{max} =$ Maximum displacement for the slider to pass over the bump

$Z_{min} =$ Minimum displacement for the slider to pass over the bump

$\theta_{max} =$ Maximum pitch angle

$\theta_{min} =$ Minimum pitch angle

$\theta_{TP} =$ taper angle

$\Theta =$ Normalized pitch angle of slider ($\theta L/ha$)

$\sigma =$ Squeeze number ($12\mu_\alpha L^2/p_\alpha h_a^2$)

REFERENCES


