FLYING CHARACTERISTICS OF A SLIDER WITH ULTRASMALL SPACING CONSIDERING SURFACE FORCE

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ABSTRACT

The generalized and approximated formula of the van der Waals pressure for a multilayered system was newly developed. The generalized formula does not require any corrections by the component materials. Applying the generalized formula to an inclined flying head slider, the dependences of the static load-carrying capacity and limit spacing of flying on the PFPE film thickness were clarified.

1. INTRODUCTION

The flying height of flying head sliders has rapidly decreased for higher recording densities in hard disk drives. In ultrasmall spacing sliders those flying height is less than about 10 nm, the sliders should be designed by considering surface forces as well as the conventional air force [1-3].

In this study, the generalized and approximated formula of the van der Waals pressure for the multilayered system is newly developed. The generalized formula does not require any corrections by the component materials, though the conventional formula [4] should be corrected when it is applied to a head disk interface (HDI) system. Applying the generalized formula to an inclined flying head slider, the dependence of the static load-carrying capacity on the PFPE film thickness is discussed. Furthermore, the existence and characteristics of the limit spacing of flying of the inclined head slider are clarified.

2. VAN DER WAALS PRESSURE FOR MULTILAYERED SYSTEM

As shown in Fig. 1, parallel media 1 and 1' (assuming solids such as disk or slider) with thin films 2 and 2' (assuming liquids such as PFPE or adsorbed liquid film with thicknesses of T and T', respectively) interact with each other through medium 3 (assuming air). The newly developed van der Waals pressure (the van der Waals force per unit area) \( p_{\text{vdw}} \) derived from Ref. [5] is given by

\[
p_{\text{vdw}} = \frac{1}{6\pi} \left( \frac{A_{11}}{(h-T-T')} + \frac{A_{22}}{(h-T')} + \frac{A_{33}}{h} + \frac{A_{12}}{(h-T)} + \frac{A_{13}}{(h-T-T')} + \frac{A_{23}}{(h-T')} \right),
\]

where \( h \) is the solid-liquid spacing between medium 1 and 1', \( A_{ij} \) are the Hamaker constants, \( k \) is the Planck constant, \( \alpha_i \) is the characteristic adsorption frequency, \( n_i \) is the refractive index of medium i. Equation (1) is a generalized or corrected equation of Eq. (11.37) in Ref. [4]. In the case of \( T \) and \( T' \to 0 \), Eq. (1) corresponds with the equation between medium 1 and 1' through medium 3.

Considering the materials used in the HDI, it is assumed that the medium 1 and 1' are the diamond-like carbon (DLC, \( n_1 = n_1' = 1.9 \)), 2 and 2' are perfluoropolyether (PFPE, \( n_2 = n_2' = 1.3 \)), and 3 is air (\( n_3 = 1.0 \)). The value of the Hamaker constants are: \( A_{11} = 2.78 \times 10^{20} \) J, \( A_{22} = A_{12} = 4.67 \times 10^{20} J \), \( A_{13} = 8.07 \times 10^{20} J \). The van der Waals pressure is attractive in this combination.

3. VAN DER WAALS FORCE ACTING ON AN INCLINED HEAD SLIDER

The van der Waals attractive force \( F_{\text{vdw}} \) acting on an infinite width inclined head slider is given by

\[
F_{\text{vdw}} = \int_0^L \int_{-\infty}^\infty p_{\text{vdw}} dx
dx
\]

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Fig. 1 Interaction between multilayered parallel surfaces

\[
A_{11} = k_{1/2323}, A_{12} = k_{1/3122}, \\
A_{13} = k_{1/3112}, A_{11} = k_{1/2112}, \\
k = \frac{3h\alpha}{8\sqrt{2}}, \\
I_{\text{vdw}} = \frac{(n^2 - n_i') (n^2 - n_e')}{(n^2 + n_i')^{12} (n^2 + n_e')^{12} ((n^2 + n_i')^{12} + (n^2 + n_e')^{12})},
\]

where \( h \) is the solid-liquid spacing between medium 1 and 1', \( A_{11} - A_{12} \) are the Hamaker constants, \( k \) is the Planck constant, \( \alpha_i \) is the characteristic adsorption frequency, \( n_i \) is the refractive index of medium i. Equation (1) is a generalized or corrected equation of Eq. (11.37) in Ref. [4]. In the case of \( T \) and \( T' \to 0 \), Eq. (1) corresponds with the equation between medium 1 and 1' through medium 3.

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\[
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dx
\]
\[ \frac{b l}{12 \pi} \left( A_{sH} \frac{h_2 + h_1 - 2(T + T')}{(h_2 - T - T')^2(h_1 - T - T')^2} + A_{sW} \frac{h_2 + h_1 - 2T}{(h_2 - T)^2(h_1 - T)^2} \right) \]

\[ + A_{sH} \frac{h_2 + h_1 - 2T}{(h_2 - T)^2(h_1 - T)^2} + A_{sW} \frac{h_2 + h_1}{h_2 h_1} \],

(5)

where \( b \) and \( l \) are the width and length of the slider, respectively, \( h_2 \) and \( h_1 \) are the solid-solid spacings at the outlet and inlet, respectively, and it is assumed that the van der Waals pressure is constant in the \( y \) direction. The value \( b = l = 1 \text{ mm} \) is used hereafter in this study.

4. STATIC CHARACTERISTICS OF AN INCLINED FLYING HEAD SLIDER

4.1 Static Load-carrying Capacity

It is assumed that the static load-carrying capacity is composed of the air bearing force \( F_{air} \) (repulsive) and the van der Waals force \( F_{vaw} \) (attractive, given by Eq. (5)). The flying height considered in this study is less than 10 nm. In this situation, the Poiseuille flow term in the molecular gas-film lubrication (MGL) equation [6] is approximately negligible and the MGL equation is simplified to

\[ \frac{d(PH)}{dX} = 0, \]

(6)

where \( P = p/\rho_a \), \( p_a \) is the ambient pressure, \( H = h_{out}/h_{out} \), \( h_{air} = h(x) - T - T' \), \( h_{out} = h_2 - T - T' \), and \( X = x/l \). Solving Eq. (6), the air bearing force \( F_{air} \) is given by

\[ F_{air} = blP_a \frac{H_2}{h_1} - \ln H_1 - 1, \]

(7)

where \( H_1 = h_{air}/h_{out} \), \( h_0 = h_1 - T - T' \). From Eqs. (5) and (7), the static load-carrying capacity \( W_{total} \) of the inclined slider is given by

\[ W_{total} = F_{air} + F_{vaw}. \]

(8)

The static load-carrying capacities \( W_{total} \) with the PFPE film only on the disk surface, i.e., the case of \( T' = 0 \), are shown in Fig. 2. In Fig. 2, the attitude of the slider is constant, i.e., \( h_1 - h_0 = 70 \text{ nm} \) (the pitch angle \( \theta = 70 \text{ mrad} \)). It is found that \( W_{total} \) has the local maximum and becomes negative according to the decrease in \( h_0 \) because the attractive van der Waals force rapidly increases according to the decrease in the surface separation. The system instability occurs at the smaller spacing than \( h_{lim} \) which gives the local maximum of \( W_{total} \) because the spring constant of the system becomes negative. The spacing at the local maximum is defined as "the limit spacing" \( h_{lim} \).

4.2 Limit Spacing and Lubricant Film Thickness

The relationship between the limit spacing \( h_{lim} \) and the lubricant film thickness \( T \) and \( T' \) is shown in Fig. 3. It is found that \( h_{lim} \) is about 1.2 nm at \( T = T' = 0 \text{ nm} \) (i.e., in case that the PFPE film is not considered) and increases according to the increase in the lubricant film thickness. It is also found that the difference between the dotted lines and the dashed or solid line shows the effect of the van der Waals force on \( h_{lim} \) and the effect is larger in the case of \( T' = 0 \text{ than} T = T' \).

5. CONCLUSION

The generalized and approximated formula of the van der Waals pressure for the multilayered system was newly developed. Applying the generalized formula to an inclined flying head slider, the dependence of the static load-carrying capacity and limit spacing of flying on the PFPE film thickness was clarified.

REFERENCES


