EFFECTS OF SOLID SURFACE ROUGHNESS ON VIBRATION TRANSFER CHARACTERISTICS OF LIQUID MENISCUS BRIDGE

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ABSTRACT

Dynamic characteristics of a liquid meniscus bridge were experimentally investigated using a dynamic meniscus force apparatus we developed. Especially, effects of solid surface roughness on vibration transfer characteristics of liquid meniscus bridge were examined.

1. INTRODUCTION

Miniaturization of machine elements has become remarkable with the progress in micromachining technologies in recent years. Surface forces (e.g., meniscus force and van der Waals force), which have been neglected in the conventional and relatively large mechanical systems, are very important in the fabrication, operation, and functions of small devices such as micro/nano-motors in MEMS/NEMS and head/disk interface (HDI) in hard disk drives (HDDs). For example, in recently developed magnetic storage systems, the spacing between the flying head slider and the disk has been decreased to less than 2 nm to facilitate ultra-high density recording. This ultra-small spacing results in the intermittent contact between the slider and the disk. The meniscus bridge of the lubricant formed between the slider and the disk affects the flying characteristics and read/write performances. Thus, knowledge of the characteristics of the surface forces, especially dynamic characteristics, is very important for the near future technologies.

As for the meniscus force, the static characteristics of the meniscus bridge have been well investigated experimentally and theoretically. On the other hand, the dynamic characteristics of the meniscus bridge have rarely been investigated.

In this study, the dynamic characteristics of a liquid meniscus bridge were experimentally investigated by an apparatus which the authors developed. Especially, the effects of solid surface roughness on the vibration transfer characteristics were clarified.

2. EXPERIMENTAL APPARATUS

The schematic diagram of the experimental apparatus for investigating the dynamic meniscus force is shown in Fig. 1. A liquid meniscus bridge is formed between a sphere surface (radius of curvature $R = 10$ mm) and a flat surface. $n$-tetradecane is used for a liquid meniscus bridge. Various roughness glasses are used for sphere surface and flat surface. The sphere is supported by a double-cantilever spring and a glass plate is put on a piezoelectric stage. The glass plate is vibrated sinusoidal by a piezoelectric stage. The natural frequency of the double cantilever spring with the sphere is 73.7 Hz. The vibration of the glass plate is transferred to the sphere through the liquid meniscus bridge. The vibration of the sphere is detected by a capacitive displacement sensor. The frequency of the vibration of the piezoelectric stage is swept by a function generator and the resonance curve can be obtained by a frequency response analyzer [1].

![Schematic diagram of the experimental apparatus for investigating the dynamic meniscus force](image-url)
3. THEORY

The meniscus force is generally a nonlinear function related to the surface separation. However, in the present study, the meniscus force function is linearized, as shown in Fig. 2, by assuming a small vibration. When the bottom surface is vibrated by $A_{in}\sin(\omega t)$ ($\omega = 2\pi f$ : excitation frequency), the amplitude ratio $A_{out}/A_{in}$ is given by

$$
\frac{A_{out}}{A_{in}} = \frac{k_{dcs} \omega^2}{\left(-m\omega^2 + k_{dcs} + k_m\right)^2 + \left(c_{dcs} + c_m\right)^2 \omega^2}.
$$

(1)

The natural frequency of the experimental system is

$$
f_n = \frac{1}{2\pi} \sqrt{\frac{k_{dcs} + k_m}{m}};
$$

(2)

where the spring constant of the double cantilever spring $k_{dcs}$ is 155 N/m and the damping coefficient $c_{dcs}$ is $1.1\times10^{-2}$ Ns/m. The spring constant $k_m$ and the damping coefficient $c_m$ of a meniscus bridge are theoretically given by the variable contact angle (VCA) model and the variable boundary position (VBP) model.

3.1 The variable contact angle (VCA) model [2]

This model conserves the volume of the liquid meniscus bridge by changing the contact angle when the spacing between the solids is periodically changed (Fig. 3).

3.2 The variable boundary position (VBP) model [3]

This model conserves the volume of the liquid meniscus bridge by changing the position of the triple line of the meniscus bridge when the spacing between the solids is periodically changed (Fig. 4).

4. SURFACE TREATMENT

In this study, we used smooth glass and rough glass as solid samples. Figure 5 is the surface topography of a smooth glass obtained by an atomic force microscope (AFM). Figure 6 is the surface profile of a rough glass measured by a surface roughness tester. The contact angle is changed by the surface roughness of a solid as shown in Fig. 7. Because the contact angle affects the vibration transfer characteristics of a liquid meniscus bridge [4], the surface roughness also affects the vibration transfer characteristics. Therefore, in this study, the contact angle is controlled by coating the glass plate with an oil repellent (Sumitomo 3M Novec EGC-1720). Without the coating the contact angle is 13 deg., while with the coating the angle is 60 deg. (Fig. 8).

In this study, rough glass is coated with oil repellent of 0.0002%.
5. RESULTS AND DISCUSSIONS

The experimentally obtained resonance curves are shown in Fig. 9, where \( h_0 = 100 \, \mu\text{m} \), the volume of the liquid, \( V \), is 0.2 mm\(^3\), \( \theta_{10} = \theta_{20} = 15^\circ \). Here, the contact angle of the upper surface is \( \theta_{10} \) and the contact angle of the lower surface is \( \theta_{20} \). The excitation amplitude \( A_{\text{in}} \) is 1 \( \mu\text{m} \). In Fig. 9, \( R_{a_s} \) and \( R_{a_p} \) are roughness of the sphere and the plate, respectively. The contact angles are controlled to approximately 15 deg. by coating the oil repellent of 0.0002%.

From Figs. 9(a) and (b), the surface roughness affects the resonant frequency, that is, the spring constant of the liquid meniscus bridge. This reason is not clear, but we consider the increase in the capillary force affects the dynamic characteristics. The surface roughness also affects the phase difference as shown in Fig. 9(c).

6. CONCLUSION

Experimental method of investigating the surface roughness effects on the vibration transfer characteristics of a liquid meniscus bridge has been established. The dependence of the resonant frequency and the phase difference on the surface roughness was shown. Namely, the surface roughness affects the spring constant and the damping coefficient of a liquid meniscus bridge.

REFERENCES