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Levitation caused by vertical vibration of a piezoelectric actuator

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Abstract
This paper describes levitation caused by a piezoelectric actuator (piezo) which vibrates in the vertical direction. A mover, which is a levitation mechanism, consists of a plate, a weight and the piezo. The air film underneath the plate which is vibrated by the piezo lifts the mechanism. The vibration amplitude and frequency varies the thickness of the air film and the levitation height. When the DC voltage is applied to the piezo, friction works against the motion of the mover in the horizontal direction. However, when the AC voltage at an appropriate frequency is applied to the piezo, the air film lifts the mover in the vertical direction and the friction does not work. The vertical levitation is larger than the static deformation of the piezo. Although the maximum voltage applied to the piezo is 100 V DC and the maximum static deformation of the piezo in the longitudinal direction is 11 μm, the mechanism levitates about 42 μm at the resonant frequency and the voltage applied to the piezo is 4 V AC. The settling time is less than 20 ms. The larger the amplitude of the applied voltage to the piezo is, the higher the levitation mechanism levitates. The levitation height and control signals are recorded simultaneously. The relation between the control signals and the levitation height is discussed. By the use of the control signals, the situation of the levitation can be detected without using a displacement sensor.

Piezoelectric actuator, levitation, vibration, friction, control signal

1. Introduction

Miniaturization of electrical appliances can be achieved by downsizing micromechanical elements. Small-scale machines and electrical equipment are usually produced by conventional large-scale production systems. The use of large-scale apparatus for the production of small parts is waste of space and energy. Therefore, small production apparatuses which consist of miniature positioning stages and miniature tools were developed [1].

In order to realize small-scale precision positioning stages, piezoelectric actuators (piezos) are used. The piezo generates small displacement and has good response. An inchworm motor using the piezos and electromagnets was developed [2]. The excited electromagnet keeps its position and the piezo pushes the non-excited electromagnet. The motion of the inchworm motor is affected by friction, since the electromagnets slide on a surface.

The friction reduction in relative motion was achieved through the use of solid lubricant coatings [3]. The control of the friction through diamond-like carbon coatings depends on both the environmental conditions and the nature of the coating, as determined by the deposition process. The friction of the surface with coatings, however, is not changed while the inchworm moves. Therefore levitation caused by vertical vibration is introduced [4]. The vertical vibration of the piezo controls the levitation which eliminates the friction.

Although the electrical signal at the resonant frequency is usually applied to the piezo, the characteristics of the levitation are unclear. This paper describes the levitation caused by the vertical vibration of the piezo at the resonant frequency. The relation between the levitation height and the control signals are discussed.

2. Experiments

A mechanism used in this paper is shown in Figure 1. The mechanism consists of a weight, a piezo, and a circular plate. They are attached by an adhesive. The weight, which simulates a mechanical element, is 40 g. The plate is 3 cm in diameter, 3 mm in thick and 5 g in weight. A stacked-type piezo (NEC-Tokin, AD050516, 20 mm long) is used. When the input voltage of 100 V_{DC} is applied to the piezo, it extends 11 μm. When the high-frequency voltage is applied to the piezo, it vibrates vertically. The squeeze film, which is generated between the ground plane and the plate, lifts the mechanism. The mechanism is placed on a flat plane on a tilt stage. The levitation height, which equals the thickness of the air film, is measured with an optical fibre displacement sensor.

The control signal generated by an oscillator is applied to the piezo through an amplifier. The levitation height, input voltage and current, phase difference between them, and power are measured, simultaneously. A power metre is used. The control frequency is 10.6 kHz, since the maximum levitation was obtained at that frequency when the 10 V peak-to-peak (V_{pp}) is applied. Since the levitation mechanism shows the nonlinear phenomenon, a theoretical model is not used. The characteristics are determined experimentally.

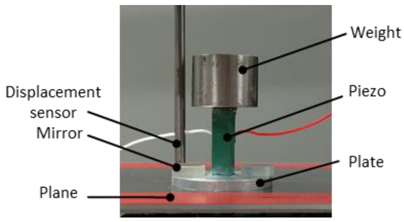

Figure 1. Levitation mechanism which levitates by the vibration of the piezo.

3. Results and discussion

3.1. Real time levitation measurement

Levitation height was measured as a function of the input voltage. When the control signal is applied to the piezo, it starts vibrating and the mechanism shows gradual levitation. The larger the input voltage is, the higher the mechanism levitates. The results of the levitation are shown in Figure 2. For the duration of this experiment the piezo was vibrating at the constant frequency of 10.6 kHz. The effective values of the input voltage are 2 V, 3 V, 4 V, which correspond to peak-to-peak voltage of 5.66 V_{pp}, 8.48 V_{pp}, 11.3 V_{pp}, respectively. Proper offsets are added in order that the input voltage should be positive. Not only the final levitation height but also the rise time varies according to the input voltage. The shortest rise time is obtained when the amplitude of the applied voltage is 4 V. The mechanism levitates 42 μm in 20 ms. The rise time obtained by the input voltage of 2 V is about 80 ms.

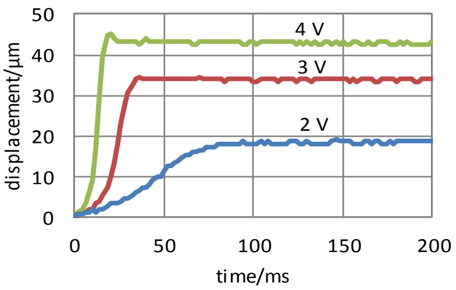

Figure 2. Experimental levitation height of the levitation mechanism.

3.2. Input signals

While the mechanism levitates, the input signals are measured. Figure 3 shows the input voltage and current. The input current obtained by the input voltage of 4 V is larger than that obtained by the input voltage of 2 V. When the input voltage is 4 V, the phase difference is about 20 degrees which is smaller than that obtained by the input voltage of 2 V.

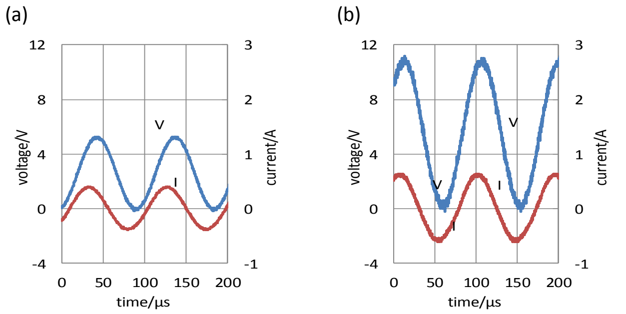

Figure 3. Input signals applied to piezo. (a) Input voltage is 2 V and (b) input voltage is 4 V.

3.3. Characteristics of input signals

Comparisons of the levitation displacement, input current, phase difference between the voltage and current, and power consumption are summarized in Figure 4. In all the figures, horizontal axis denotes the input voltage applied to the piezo. The piezo vibrates in the vertical direction at the constant frequency of 10.6 kHz.

While the input voltage is smaller than 1.4 V, the mechanism does not levitate as shown in Figure 4(a). It is clear that levitation height increases with increasing applied voltage. There is an increase in displacement from 0.2 μm at 1.4 V to 32 μm at 2.8 V, after which there is a more gradual increase in displacement. A similar trend is observed when the phase difference vs. input voltage is plotted in Figure 4(c).

In Figure 4(b), input current is proportional to the applied voltage blow 1.4 V. An inclination is changed at 1.4 V, where the dynamics of the levitation mechanism is changed. In a similar way, the power consumed in the mechanism consists two straight lines as shown in Figure 4(d). One line remains approximately 0 W from 0 V to 1.2 V, and the other line increases from 1.4 V to 4.0 V.

Since the piezo is a capacitive load, it consumes small electric power. The mechanism levitating by the squeeze film effect consumes a lot of power. The levitation height however saturates because of fluid mechanics in the air film.

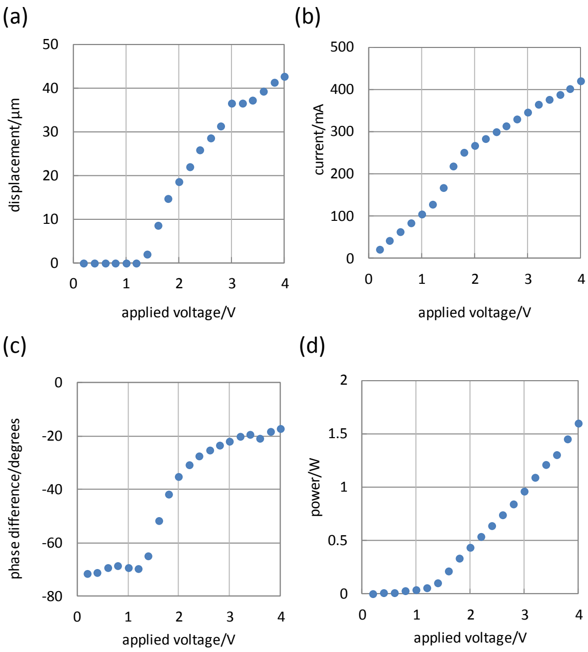

Figure 4. Experimental data of the levitation mechanism.

4. Summary

Levitation caused by the vertical vibration of a piezoelectric actuator was described. The mechanism levitated about 42 μm when 4 V AC was applied to the piezo at the constant frequency of 10.6 kHz. The phase difference between the input voltage and current varied according to the input voltage. The phase difference and power changed when the mechanism levitated. These measured data therefore are important, since they include the information about the levitation height of the mechanism. For future work, the mathematical model which is based on fluid mechanics should be studied so as to estimate the levitation height of the levitating mechanism without using displacement sensors.

Acknowledgement

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