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Control signal of levitation actuator using vertically vibrating piezoelectric actuator

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Abstract
Control signal of a levitation actuator is described in this paper. The levitation actuator is used to realize a non-contact conditions. The vertically vibrating stacked-type piezoelectric actuator (piezo), a weight, and a circular plate consist the levitation actuator. The weight is about six times heavier than the plate. The piezo is sandwiched in the weight and the plate. The piezo vibrates around the resonant frequency. Squeeze air film is generated underneath the plate, and the positive pressure of the squeeze air film underneath the plate supports the levitation actuator. The AC voltage with variable frequency is applied to the piezo. The input signal and the levitation height are measured simultaneously. The instantaneous power and levitation height are recorded and discussed according to the drive frequency. The experimental results revealed the following points. (I) The levitation height of the actuator is about 1 μm, although the amplitude of the vibration of the plate is as small as 0.1 μm. (II) The levitation height depends on the mass of the weight. (III) The electric power applied to the piezo shows similar trend of the levitation.

Levitation actuator, levitation, piezoelectric actuator, electric power, frequency

1. Introduction

Many functions are integrated in the limited size of industrial products and electrical appliances. Small production systems is suitable for a versatile and compact movement mechanism. A precise motion is usually realized by stacked-type piezoelectric actuators (piezos). The piezos are used in a lot of precision machines. If a levitation function is added to the mechanism, energy loss and positioning error due to friction during a motion can be reduced.

Levitation caused by a vertical vibration of the piezo was introduced to realize a levitation actuator for a non-contact mechatronic system [1-3]. The electrical signal at a resonant frequency is applied to the actuator. A displacement meter was used to measure the levitation height of the levitation actuator. A measurement method without using a displacement meter will be required when the levitation actuator is installed in a micro-robot, micro-machine, and micro-system.

This paper describes the relationship between the power, power factor, and the levitation height of the levitation actuator.

2. Structure of the levitation actuator

Figure 1 shows a photograph of the levitation actuator. The levitation actuator consists of a disk-shaped plate, a weight, and a piezo. They are attached with cyanoacrylate adhesive. The mass of the weight is 47.1 g. The diameter, thickness, and mass of the plate are 30 mm, 3 mm, and 4.0 g, respectively. The total length of the entire levitation actuator is 38 mm and the mass is 47.1 g. The piezo (NEC-tokin,AE0505D16DF) deforms 11.6 μm when 100V DC is applied. Three weights, 26.8 g, 47.1 g, and 79.4 g are tested.

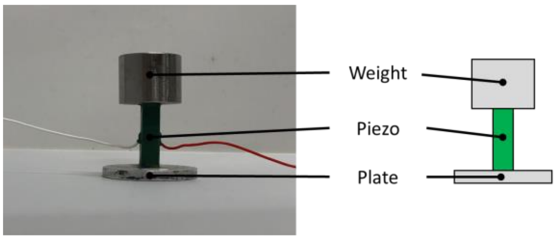

Figure 1. Levitation actuator

3. Principle of levitation

When a high-frequency voltage is applied to the piezo, it vibrates in the vertical direction. The plate attached to the piezo vibrates synchronously. The vibration of the plate generates positive pressure between the plate and the ground surface, and an air film is formed between the plate and the ground surface, causing the levitation actuator to float. This phenomenon is called the squeeze film effect, and the film is called a squeeze air film. The squeeze film effect continues while high frequency voltage is applied to the piezo, and the actuator continues to levitate. At the beginning of the levitation, the weight starts vibrating by the piezo vibration, and the actuator starts levitating. Then, the piezo keeps vibrating and the actuator continues levitation. Finally, the constant levitation is established.

4. Experimental method

The power and power factor (Q-factor) are measured by a power meter, and levitation height of the levitation actuator is measured by a laser displacement meter (Keyence, LK-G3000 series, 0.05% of full scale linearity). Figure 2 shows the definition of the levitation height. The levitation height is measured at the

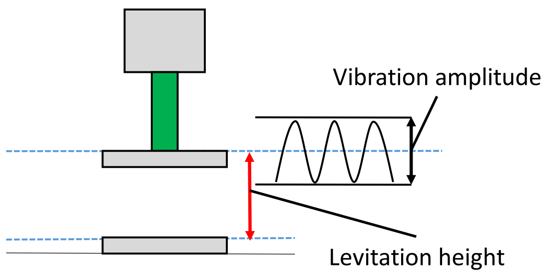

Figure 2. Definition of levitation height

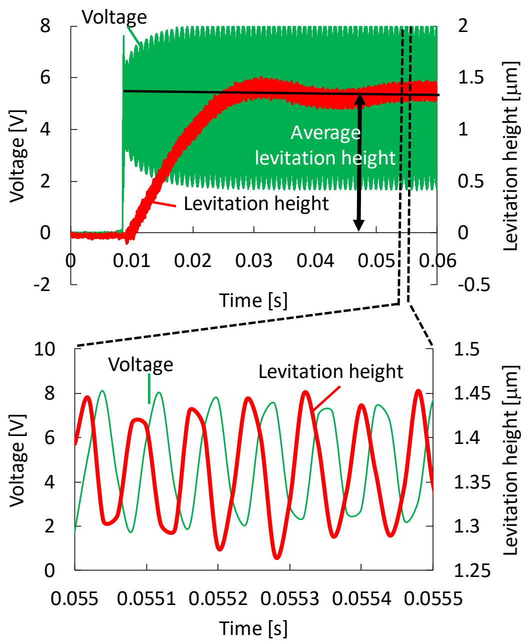

Figure 3. Result of levitation height measurement

top surface of the plate. The levitation height is the vertical displacement of the plate, and is defined from the average value for one second (1 s). This is because the plate vibrates at the frequency applied to the piezo and the instantaneous value of the levitation height oscillates. Vibration amplitude is defined as shown in Figure 2.

The voltage from a function generator is passed through an amplifier to apply an AC voltage to the piezo. The input voltage to the piezo is a sinusoidal voltage of 8 V peak-to-peak and an offset of 5 V. The frequency of the input voltage is between 1 kHz and 15 kHz, in 0.2 kHz increments. Since the weight is much heavier than the plate, the vibration amplitude of the weight is small.

5. Experimental results

Figure 3 shows the levitation height of the actuator with a 47.1 g weight. The signal applied to the piezo is sinusoidal wave of 8 V peak-to-peak with 5 V offset and 12.8 kHz. At the beginning of the operation, the voltage begins to oscillate and then the levitation actuator starts levitating. The measured height is synchronized with the input signal. The average levitation height is 1.32 μm and the vibration amplitude of the plate is 0.19 μm. The ratio of the amplitude to the average height is 6.8. Small vibration amplitude of the plate causes large levitation.

Figure 4 shows the power, power factor, and levitation when the frequency is from 1 kHz to 15 kHz in 0.2 kHz step. The horizontal axis indicates the frequency, the vertical axis indicates

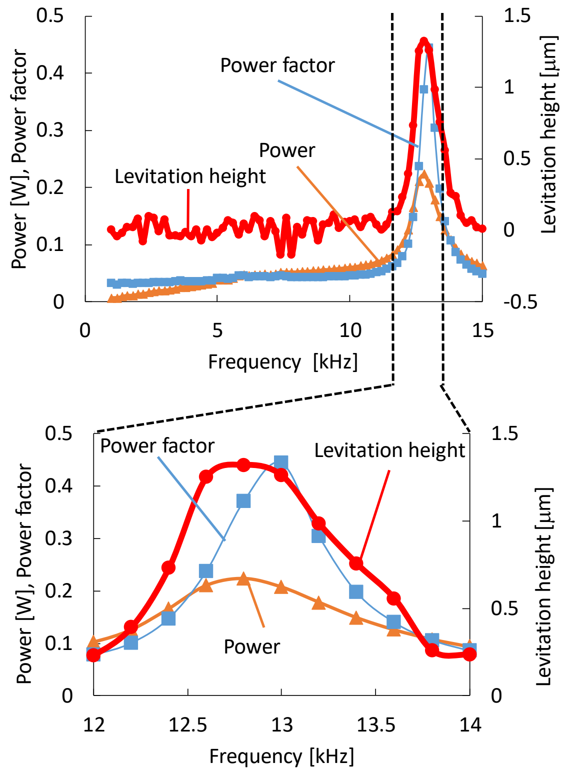

Figure 4. Power, power factor, and levitation height

Table 1 Levitation height obtained by different weight

Weight [g]	Levitation height [μm]
26.8	1.98
36.9	1.32
79.4	1.03

the power, power factor, and the levitation height. Both the levitation height and the power are maximum at 12.8 kHz. The levitation height is 1.32 μm and the power is 0.22 W. The maximum power factor is 0.44 at 13 kHz. The power and power factor are large during the levitation, and they show similar trend.

Table 1 summarizes the results obtained by three different weight. The maximum levitation heights obtained by different frequency are summarized. The heavy weight reduces the levitation height.

6. Summary

The purpose of this paper was to find out the relationship between the power, power factor, and the levitation height of the levitation actuator during levitation. Both the levitation height and the electric power were maximum at 12.8 kHz. The levitation height was 1.32 μm and the power was 0.22 W. While the actuator was levitating, the power was large and the electric power consumed in the levitation actuator showed similar trend with the levitation height. In future, theoretical power consumption is discussed, and levitation height estimation is realized using electric power measurement. This work was supported by JSPS KAKENHI Grant Number 21K03972.

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