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Characteristics of acoustic levitation system using piezoelectric actuator

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Abstract

This paper describes the characteristics of an acoustic levitation system that utilizes vertically vibrating piezoelectric actuator. The system is designed to achieve non-contact conditions. The electrical signals of the system are used to estimate the levitation height. The levitation system is composed of a vertically vibrating stacked-type piezoelectric actuator (piezo), a weight, and a plate. The piezo is sandwiched between the weight and the plate, and vibrates at the appropriate frequency. A squeeze air film is generated underneath the plate, allowing the system to levitate. At the beginning of the levitation, the weight vibrates due to the piezo vibration, causing the system to start levitating. Subsequently, the piezo continues to vibrate, and the positive pressure of the squeeze air film underneath the plate supports the levitation system. The piezo can be driven with variable frequency and amplitude. To evaluate the performance of the system, we simultaneously measure the instantaneous levitation height, voltage, and current applied to the piezo. The experimental results revealed the following: (i) The levitation height can be controlled not only by adjusting the amplitude of the applied voltage to the piezo but also by varying the frequency of the control signal. (ii) The levitation height can be estimated between 11 kHz and resonant frequency by measuring the current and applied voltage, which are used to calculate the admittance. (iii) The maximum estimation error is about 0.5 μm.

Levitation actuator, levitation, piezoelectric actuator, control signal

1. Introduction

To meed the demand for multi-functional products in small sizes, small production systems with miniature tools and positioning devices are developed. Precision motion devices use stacked-type piezoelectric actuators (piezos) for small displacement and rapid response. An inchworm motor that utilizes piezos and electromagnets has been developed to enable precise motion control [1]. However, the motion of the inchworm can be affected by friction. To overcome this issue, a levitation technique that eliminates the friction has been introduced [2]. While stable acoustic levitation has been achieved for non-contact manipulation [3] and the acoustic levitation has been measured and evaluated by a camera [4], the levitation height caused by vibration remains unmeasured and anassessed.

The purpose of this paper is to investigate the relationship between levitation height and electrical signals, with the goal of achieving sensorless levitation height estimation. Levitation using piezo vibration is examined, and levitation height and electrical signals are measured as a function of frequency and applied voltage.

2. Levitation system

Figure 1 shows a levitation system and its components. The system comprises a disk-shaped plate, a weight, and a piezo, which are bonded together using cyanoacrylate adhesive. The weight has a mass of 36.9 g, while the plate has a diameter, thickness, and mass of 30 mm, 3 mm, and 4.0 g, respectively. The entire levitation actuator has a total length of 38 mm and a mass of 47.1 g. The piezo used in the system is AE0505D16DF (NEC-tokin), which exhibits a deformatnion of 11.6 μm when 100 V DC is applied.

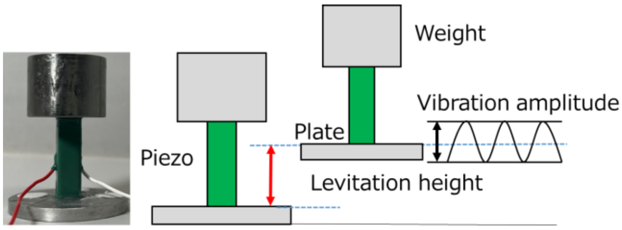

Figure 1. Levitation system.

An oscillator generates a signal, which is then amplified and applied to the piezo. While a high-frequency voltage is applied to the piezo, it vibrates vertically, causing the plate to vibrates. The vibration generates positive pressure underneath the plate, creating an air film known as a squeeze film that allows the levitation system to float. The squeeze film effect persists as long as the high-frequency voltage is applied to the piezo, enabling the system to continue levitating. The levitation height is defined as the averaged height of the plate, evne though the plate vibrates vertically in synchronization with the piezo's vertical vibration. It should be noted that the levitation height is typically much larger than the vibration amplitude.

3. Experiment

The levitation height of the plate is measured by a laser displacement sensor (Keyence, LK-G40A). The current is measured with a current sense resistor (10 mΩ). Time domain signals are collected using a recorder, and the admittance and phase difference are calculated offline. The amplitude of the input voltage is varied from 5.0 V to 15.0 V with a 2.5 V interval, and the frequency is scanned from 10.0 kHz to 14.0 kHz with a 0.1 kHz interval.

4. Experimental results

4.1. Voltage, current and levitation height

Figure 2 shows the waveforms of the applied voltage, measured current, and measured levitation height at the frequency of 11.9 kHz. The amplitude of the applied voltage is 4.8 V_{pp} (peak-to-peak) with a 2.4 V offset. The amplitude of the current is 1.0 A_{pp}. The levitation height is represented by a vertical displacement of 1.8 μm, while the amplitude of vibration is 0.4 μm_{pp}. Therefore, the levitation height is 4.5 times larger than the amplitude of vibration.

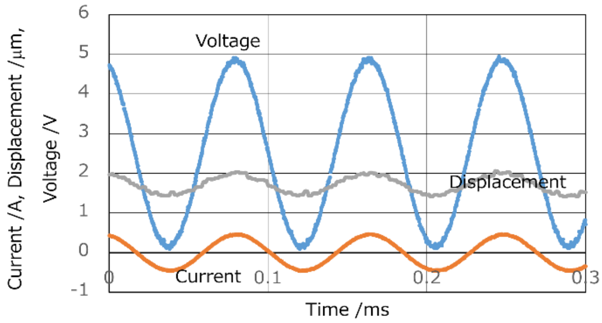

Figure 2. Voltage, current and levitation height.

4.2. Levitation height

Figure 3 shows the levitation height. The maximum levitation height is achieved at a voltage of 15 V and a frequency of 11.4 kHz. As the voltage is decreased, the frequency at which the maximum levitation heights are obtained increases, and the levitation height of the system decreases.

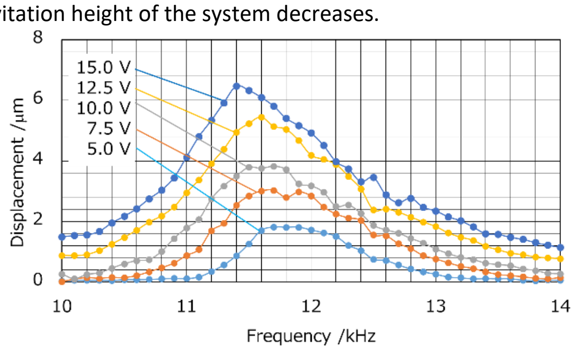

Figure 3. Levitation height.

4.3. Admittance and phase difference

Figure 4 shows the admittance, which is calculated by dividing the instantaneous current by the instantaneous applied voltage. The resonance frequency, which is the frequency at which the maximum admittance occurs, is in agreement with the frequency at which the maximum height is achieved, as shown in Figure 3.

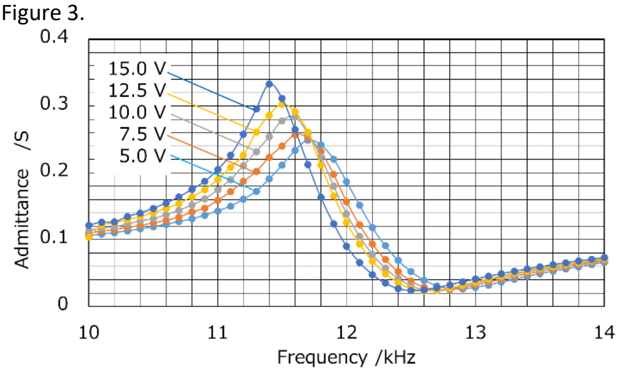

Figure 4. Frequency characteristics of admittance.

The phase difference between the applied voltage and the current is shown in Figure 5. The phase difference exhibits a difference trend, with a minimum value of about -45 degrees. This is attributed to the power consumption of the levitation system.

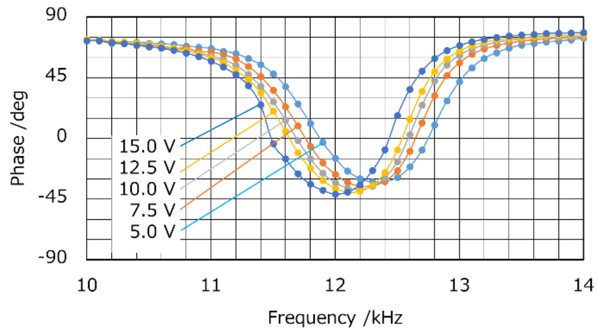

Figure 5. Frequency characteristics of phase difference.

4.4. Levitation height estimation

Figure 6 shows the relationship between levitation height and the admittance of the electrical signals. The data points are plotted between 11 kHz and individual resonant frequencies, and regression lines are drawn for each input voltage. The admittance, which is calculated from both the current and voltage, enables the real-time estimation of the levitation height, although Figure 6 was obtained offline. The maximum estimation error, determined by the difference between the estimated line and plotted data, is about 0.5 μm.

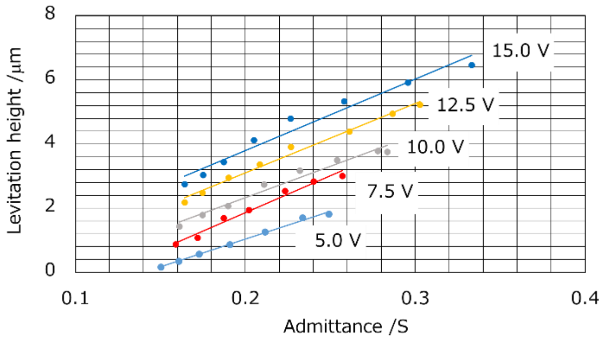

Figure 6. Levitation height versus admittance.

5. Conclusions

In this paper, we have presented the characteristics of an acoustic levitation system that uses a piezoelectric actuator to achieve sensorless levitation height estimation. Simultaneous measurements of the current flowing to the vibrating piezo and the levitation height were conducted, and the characteristics of the levitation system were clarified based on the measurement results. The parameters controlled were the frequency and amplitude of the voltage. These results are valuable for estimating the levitation height from the control electrical signals, although further improvements in the accuracy of the model are expected in future research.

Acknowledgement

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References

[1] Matsuda R, Torii A, Mototani S, Doki K 2022 euspen 22nd Int. Conf., Geneva, Switzerland P2.24, 231-232

[2] Torii A, Sone S, Doki K, Mototani S 2015 euspen 15th Int. Conf., Leuven, Belgium P4.30, 273-274

[3] Li H, Wang Y, Li Y, Sun W, Shen Y, Zeng Q 2022 Int. J. Mechanical Sciences, 225, 107358

[4] Furumoto T, Hasegawa K, Makino Y, Shinoda H 2019 IEEE Robotics and Automation Letters, pp. 81-88, Vol. 4, Issue 1,