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Levitation estimation using electrical characteristics of the levitation actuator with stacked piezoelectric element

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Abstract

This paper describes levitation estimation for a levitation actuator that can be used in non-contact mechatronic systems. The levitation height is estimated using electrical characteristics. The levitating actuator consists of a vertically vibrating stacked piezoelectric actuator (piezo), a weight and a disc plate. The piezo is sandwiched between the weight and the disc plate. The levitating actuator is levitated by applying the appropriate voltage and frequency to the piezo. A squeeze air film is generated below the disc plate. The positive pressure of the squeeze air film under the disc plate supports the levitation actuator. At the beginning of levitation, the piezo vibration causes the weight to start vibrating and the actuator begins to levitate. Afterwards the piezo continues to vibrate and the levitation actuator continues to levitate. As the integration of levitation height sensors into the non-contact mechatronic systems is difficult in practice, levitation estimation technology plays an important role. The instantaneous levitation height and electrical signals are measured simultaneously. The power, phase difference and admittance are determined based on the voltage and current supplied to the levitation actuator, and the levitation height is estimated. The results of the experiments reveal the following. (i) The higher the applied voltage is, the higher the levitation height and the wider the levitation frequency band is. (ii) The levitation height of the levitation actuator can be estimated by power and admittance. (iii) The maximum levitation height is revealed to be correlated with the phase difference of the levitation actuator.

Levitation actuator, estimation levitation height, piezoelectric actuator, electrical characteristics

1. Introduction

The demand for miniaturization of industrial robots is increasing. This is because products are becoming miniaturized at manufacturing sites with space constraints and small lot production of many products. The use of piezoelectric elements (piezos) in precision mobile robots enables miniaturization and micro displacement. We are developing inchworm robots using piezo and electromagnets to enable precise movement [1]. However, the inchworm robot is affected by friction while moving. Therefore, we propose a moving actuator with levitation in order to reduce the effects of friction [2]. The levitation actuator levitates by generating a film of air. A non-contact platform using near-field acoustic levitation has been proposed[3]. However, there has been no estimation of the levitation height for levitation systems using vibration.

The purpose of this paper is to clarify the relationship between the levitation height and electrical characteristics of the levitation actuator. We propose a sensorless method for estimating the levitation height.

2. Levitation actuator

Figure 1 shows the levitation actuator. It consists of a weight, piezo, and plate. Each component is fixed by cyanoacrylate adhesive. The mass of the weight is 36.9 g. The thickness of plate is 3 mm, and its weight is 5.6 g. The diameter of plate is 30 mm. The total length of the levitation actuator is 38 mm and the weight is 47.6 g.

The piezo used in the levitation actuator is AE0505D16DF (TOKIN), which exhibits a deformation of 11.6 µm when 100 V_{DC} is applied. When a sinusoidal voltage is applied to the piezo, it generates the amplitude in vertical vibration. In conjunction with the vibration of the piezo, the plate also vibrates. As the plate vibrates, positive pressure is generated between the plate and the floor surface. The squeeze film effect which generates a film of air causes the plate to levitate. The levitation actuator continues to levitate by continuously applying the appropriate voltage and frequency. The levitation height is measured at the top of the plate by a displacement sensor (Keyence LK-H053). 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 1 (b). Time domain signals are collected using an oscilloscope and recorder.

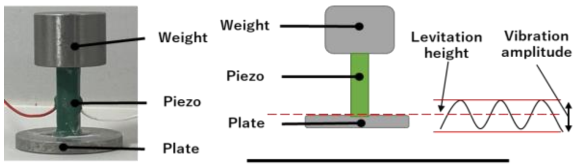


Figure 1. (a) Levitation actuator. (b) Definition of levitation height

3. Experiment and results

A sinusoidal voltage is applied to the levitation mechanism from a bipolar power supply. The amplitude of the input voltage is varied from 4 V to 10 V with a 2 V interval, and the frequency is scanned from 10 kHz to 16 kHz with a 0.1 kHz interval. Electric properties, such as voltage, current, power, admittance, and phase difference between the voltage and current, are measured by a power meter (Hioki, PW3335).

3.1. Levitation height

Figure 2 shows the levitation height. The maximum levitation height is 33.8 μm at 12.7 kHz when 10 Vpp was applied. As the voltage applied to the levitation actuator increases, the levitation height also increases. This phenomenon indicates that the frequency band in which the levitation is obtained is widening.

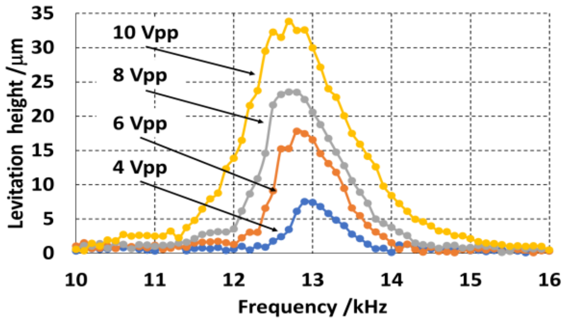


Figure 2. Levitation height

3.2. Power

Figure 3 shows the electric power. The maximum power is 2.6 W at 12.5 kHz when 10 Vpp is applied. It shows that the change in power generally corresponds to the change in the levitation height in Fig. 2. As the applied voltage increases, the frequency showing the maximum value of both the levitation height and power decreases.

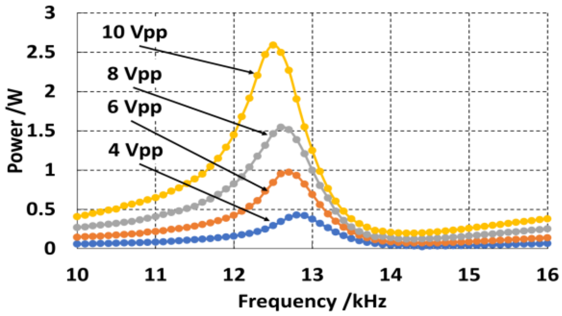


Figure 3. Power

3.3. Admittance and Phase difference

Figure 4(a) shows the admittance, which is calculated by dividing by the instantaneous current by the instantaneous voltage. The frequencies of the maximum power and the maximum admittance almost agree.

Figure 4(b) shows the phase difference. The frequency where the phase difference equals zero and the frequency where the maximum levitation height agree. As the same with the power in Fig.3 and the admittance in Fig.4(a) and the phase difference in Fig.4(b), the curves also shift to lower frequency side as the applied voltage increases. This phenomenon shows that the levitation height at the resonant frequency is higher than that at the anti-resonant frequency.

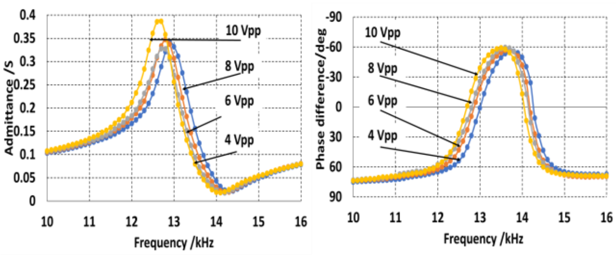


Figure 4. (a)Admittance (b)Phase difference

4. Levitation estimation

Figure 5 and Figure 6 show the levitaiton height estimation equations. In Fig. 5, the levitation height (y) is estimated by power consumed (x) and the voltage applied. In Fig. 6, the levitation height (y) is estimated by the admittance (x) and the voltage. The estimating equations are obtained from the data shown in Fig. 2 where the levitation height from 3 μm to the maximum and the corresponding data in Fig. 3 and Fig. 4. The difference between the estimation line and measured plots indicates estimation error.

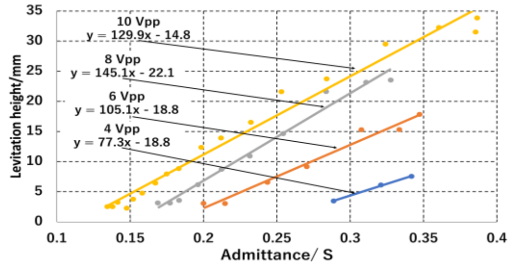


Figure 5. Power versus levitation height

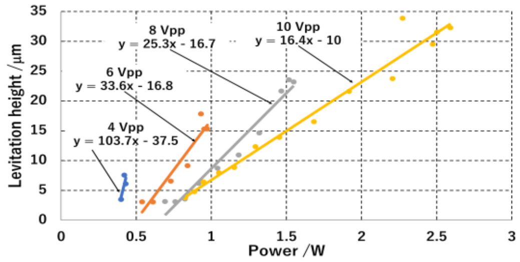
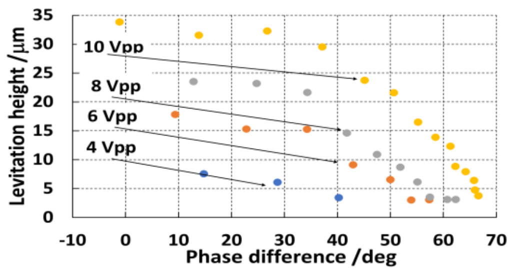


Figure 6. Admittance versus levitation height

Figure 7 shows the relationship between phase difference and levitation height. The data shown in Fig. 2 and Fig. 4(b) are summarized. As the phase difference approachs zero, the levitation height increases. Since the phase difference and power are related through a trigonometric function, the relationship between the phase and the levitation will be studied in detail in future.

Figure 7. Phase difference versus levitation height



5. Conclusions

In this paper, we described a levitation height estimation using the characteristics of the levitation actuator to achieve sensorless operation. By measuring the levitation height, power, admittance of the actuator, and phase difference, we showed the possibility of the sensorless levitation height estimation and levitation height control. This work was supported by JSPS KAKENHI Grant 21K03972.

Reference

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