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Nonlinearity of drive signals applied to levitation actuator using piezoelectric element

Akihiro Torii[1], Hidetoshi Miyata[1], Shota Aoki[1], Suguru Motani[1], Kae Doki[1]

[1]*Aichi Institute of Technology, Japan*

Torii@aitech.ac.jp

Abstract

The aim of this paper is to clarify the relationship between the levitation height of the levitation actuator and the drive signals. The levitation actuator is used to realize a non-contact mechatronic system. It is composed of a vertically vibrating piezoelectric element (piezo), an inertial body, and a disc plate. The piezo is sandwiched between the inertial body and the disc plate, and is driven with variable frequency and voltage. The levitation actuator can levitate by the appropriate voltage and frequency. Squeeze air film is generated underneath the disc plate. The positive pressure of the squeeze air film supports the levitation actuator. The inertial body starts vibrating by the piezo vibration, causing the actuator to start levitating. The piezo continues to vibrate, maintaining the levitation. The levitation height is controlled near the resonance frequency. This paper describes the mechanical and electrical characteristics while the drive frequency of the input signal varies continuously. The levitation height increases rapidly near the resonance frequency while the drive frequency increases. When the drive frequency is decreased, there is no sudden change in the levitation height. The current increases or decreases near the frequency at which the maximum levitation height is obtained. The phase difference between voltage and current crosses zero near the resonance and anti-resonance frequency.

Levitation actuator, piezoelectric element, drive frequency sweep, squeeze air film, mechanical and electrical characteristics

1. Introduction

Electronic devices have been miniaturized. There has been a demand for the miniaturization of industrial equipment. We have been developing a miniature positioning actuator using piezoelectric elements (piezos) [1]. The use of piezos in actuators enables compact designs and precise motion in micromechanisms. However, the micromechanisms are affected by friction. To solve the friction problem, we have proposed a levitation actuator using a piezo to eliminate friction [2]. The levitation actuator achieves levitation by generating an air film. However, the levitation characteristics concerning drive source have not yet been fully analysed. The purpose of this paper is to clarify the effect of the drive frequency of the input signal on the levitation actuator. We describe the relationships among levitation height, current, and the phase difference between voltage and current.

2. Levitation actuator and experiment

Figure 1 shows the levitation actuator. It consists of an inertial body, a piezo, and a disc plate. Each component is bonded using cyanoacrylate adhesive. The inertial body has a mass of 36.9 g, a diameter of 20 mm, and a length of 15 mm. The disc plate has a mass of 5.7 g, a diameter of 30 mm, and a thickness of 3 mm. The overall length is 38 mm, and its total weight is 47.3 g. The piezo used in the levitation actuator is the AE0505D16DF (TOKIN), which exhibits a deformation of 11.6 μm when 100 VDC is applied. When a sinusoidal voltage is applied to the piezo, it generates vertical vibration with a corresponding amplitude. The vertical amplitude of the piezo induces vibration in the disc plate. As the disc plate undergoes rapid oscillations, the air between the disc plate and the floor is squeezed outward, generating positive pressure. Consequently, the time-averaged pressure of the air between the two flat surfaces becomes higher than the surrounding pressure, forming an air film. This phenomenon is known as the squeeze-film effect. The levitation actuator remains levitated by continuously applying an appropriate voltage and frequency.

A sinusoidal voltage from a function generator is amplified via a high-speed bipolar amplifier (NF Corp., HSA4052). The amplitude of the input voltage is 5 Vpp, including a DC offset of 2.5 V. The drive frequency sweeps between 10 kHz and 15 kHz, and the sweep time is 0.5 s and 1 s to 4 s at one second interval. The levitation height is defined as the vertical displacement at the top of the plate, and is measured by a displacement meter (Keyence, LK-H053). The current is measured with an ammeter (Tektronix, TCPA300). The input voltage, current, and height displacement are recorded by a scope coder (Yokogawa, DL850).

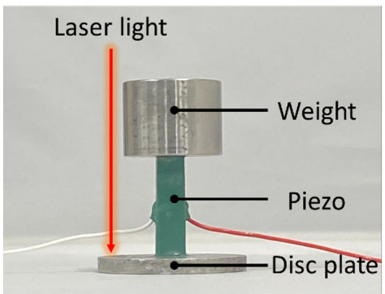
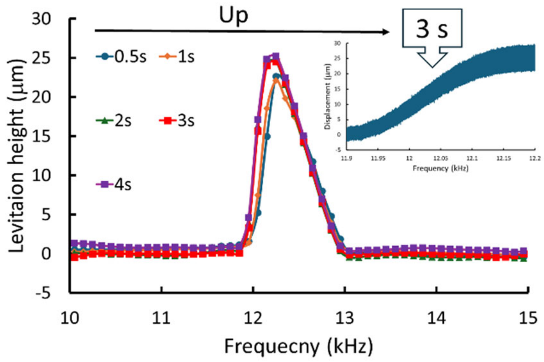


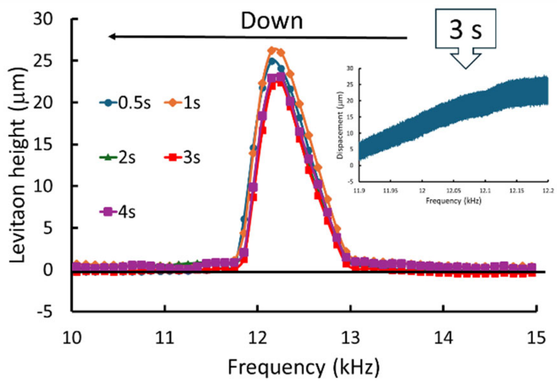
Figure 1. Levitaion actuator

3. Experimental results

Figure 2 shows the levitation height plotted as 0.1 kHz average. Figure 2a shows the result obtained by the up-sweep while the frequency increases, and Figure 2b shows the down-sweep while the frequency decreases. The levitation actuator floats between 12 kHz and 13 kHz, and the maximum levitation height is about 25 µm at 12.3 kHz. The change in levitation height is not significantly affected by sweep time. As there is no significant difference in the levitation height due to the differences in sweep time, we use the up-sweep of 3 s (three second) for the following experiment. In up-sweep case, the levitation height changes sharply around 12 kHz. The slope at 12.0 kHz is 140 µm/kHz as shown in inset of Figure 2a, although that is 90 µm/kHz in Figure 2b. The difference is caused by the jumping phenomena of the piezo [3].



a)



b)

Figure 2. Levitation height, a) up-sweep and b) down-sweep

Figure 3 shows the waveform of the disc plate displacement and current when the input frequency is 12.3 kHz. The amplitude of the input voltage is 5 Vpp, including a DC offset of 2.5 V. The vibration of the disc plate is a sinusoidal wave. The average of displacement is 21.5 µm, and the amplitude is 7.0 µm peak-to-peak. The root-mean-square, RMS, of current is about 0.42 A.

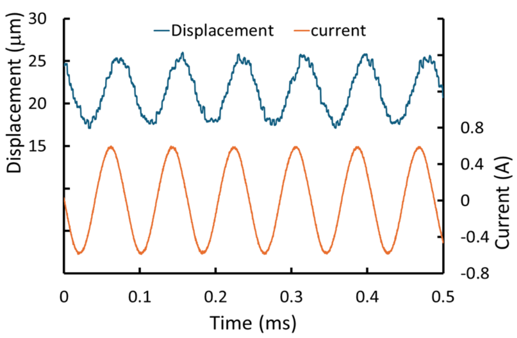


Figure 3. Displacement of disc plate and current

Figure 4 shows the current obtained by up-sweep. The white plots show RMSs of current, which are calculated at interval of 0.1 kHz. While the frequency increases, the current increases and achieves the maximum, then decreases to the minimum, and finally gradually increases again. The current increases and decreases between 12 kHz and 13 kHz, while the actuator is levitating. The maximum current is 0.5 A RMS at 12.2 kHz, and the minimum of current is 0.08 A RMS at 13.2 kHz.

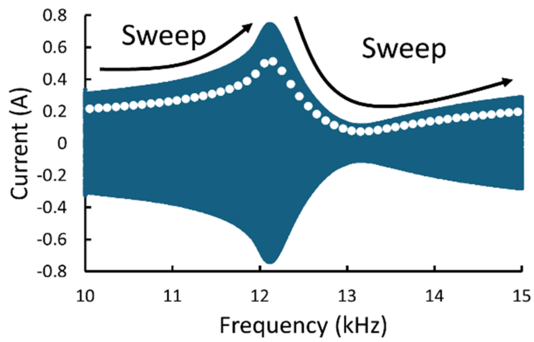


Figure 4. Current (Up-sweep for 3 s)

Figure 5 shows the phase difference between voltage and current. The phase difference shows capacitive lower than 12 kHz and higher than 13 kHz. The minimum phase difference of the inductive characteristics is about -20 deg at 12.6 kHz. The resonance frequency, shown in the red dashed line, is 12.3 kHz and the anti-resonance frequency, in green dashed line, is 13.0 kHz. The resonance frequency almost corresponds with the frequency of the maximum levitation height. The anti-resonance frequency does not corresponds with any mechanical motion. The levitation actuator does not able to float at the frequency smaller than the resonance and larger than the anti-resonance frequency.

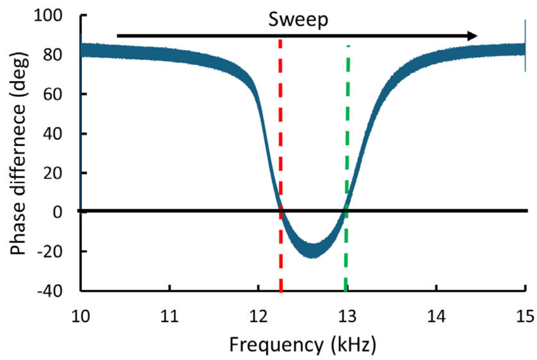


Figure 6. Phase difference (Up sweep for 3 s)

4. Conclusions

We described the relationship between mechanical and electric characteristics while the input drive frequency of the levitation actuator sweeps. There was little difference in the levitation height with sweep time. The levitation height increased rapidly near the resonance frequency with up-sweep input, while no similar phenomena observed with down-sweep input. The input current was maximum at the resonance frequency and was minimum at the anti-resonance frequency. We showed the levitation actuator is inductive between the resonance frequency and anti-resonance frequency while it is capacitive lower than the resonance frequency and higher than the anti-resonance frequency.

References

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