euspen's 17th International Conference & Exhibition, Hannover, DE, May 2017
www.euspen.eu

Levitation characteristics of an actuator in a non-contact mechatronic system

Akihiro Torii [1], Kento Tanaka [1], Suguru Motoani [1], Kae Doki [1]

[1] *Aichi Institute of Technology, Aichi, Japan*

torii@aitech.ac.jp

Abstract

In this paper, we describe the levitation characteristics of an actuator which can be used to realize a non-contact mechatronic system. A levitation height is measured with a displacement sensor, and electrical control signals are investigated by a frequency response analyser. From experimental results, both the levitation height and electrical characteristics shows non-linearity. Not only frequency of the control signal but also the amplitude of the input voltage changes the levitation, admittance and phase. These results will be used to estimate drive condition of the actuator in future.

Levitation piezoelectric actuator, control signal, frequency

1. Introduction

Small production apparatuses which consist of miniature positioning stages and miniature tools are developed. 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 is developed [1]. 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.

Levitation caused by the vertical vibration of a piezo is introduced so that the friction is reduced [2]. The electrical signal at a resonant frequency is usually applied to the piezo. However, the levitation changes according to the input signal. This paper describes the levitation as a function of input voltage over a range of control frequency. The relation between the levitation height and the control signals are discussed.

2. Levitation mechanism

A levitation 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 a cyanoacrylate 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. The piezo vertically vibrates by high-frequency voltage. The squeeze film generated between a ground plane and the plate lifts the mechanism. The mechanism is placed on a flat plane on a tilt stage. The vertical position of the plate, which equals the levitation height, is measured with a laser displacement sensor (KEYENCE, LK-G5000 series). The vertical position of the weight is also measured. Once the mechanism levitates, the squeeze film effect causes the gap large. The electrical conductivity between the plate and the plane is measured in order to show the generation of non-contact condition.

The control signal is generated by an oscillator, and is applied to the piezo through an amplifier. The levitation height, input voltage and current, and phase difference between them are measured, simultaneously. The actual voltages applied to the piezo are recorded. A frequency response analyser (FRA) which measures the gain and phase response characteristics with respect to frequency of the levitation mechanism. A frequency swept sinusoidal waveform is applied to the piezo, and response signal is examined.

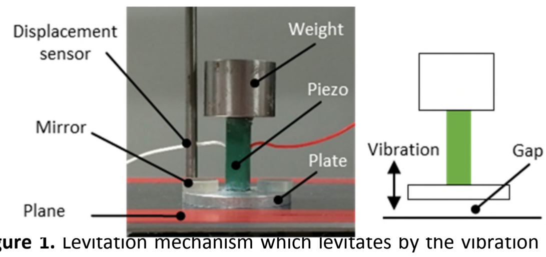

Figure 1. Levitation mechanism which levitates by the vibration of the piezo.

Figure 2 shows a vertical position of the plate and that of the weight. A voltage applied to the piezo is 4 V peak-to-peak (V_{pp}) and a drive frequency is 10 kHz. The averaged vertical position of the plate is about 2.6 μm, which is determined as a levitation height of the mechanism. The vibration amplitude of the plate is 2.0 μm peak-to-peak (μm_{pp}). This phenomenon shows that the levitation mechanism is levitating and is not in contact with a surface. The vibration amplitude of the weight, about 0.8 μm_{pp}, is smaller than that of the plate. The amplitude of the plate is larger than that of the weight, since the plate is lighter than the weight.

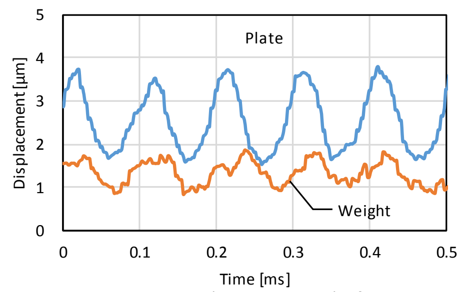

Figure 2. Vertical position (displacement) of the plate and weight of the levitation mechanism.

3. Levitation height measurement

A displacement of the plate of the levitation mechanism is measured by changing the amplitude of the control signal. Figure 3 shows experimental results as a function of frequency. The levitation of the plate varies significantly. For example, the levitation height at 11.5 kHz is 46 μm by 6 V_{pp}, 26 μm by 8 V_{pp}, and 0 μm by 10 V_{pp}, respectively. The larger the amplitude is, the smaller the levitation is. The vertical displacement is not proportional to the voltage applied to the piezo at a drive frequency. The maximum levitation height obtained by every input voltage is summarized in table 1. As the input voltage increases, the frequency which shows large levitation height decreases.

These results indicate nonlinearity of the levitation mechanism, and show similar results published by Priya [3]. In our experimental conditions, a stacked-type piezo is integrated and large piezo deformation is used. Therefore, the drive frequency ranges from 6 kHz to 14 kHz, and quality factor (Q) is not so large. The previously published results used piezo material with large Q and the nonlinearity was discussed in a very narrow frequency range [3].

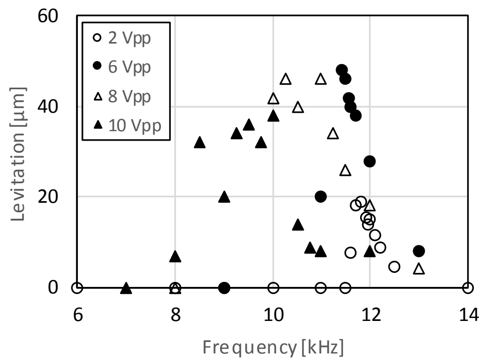

Figure 3. Vertical position (displacement) of the plate and weight of the levitation mechanism.

Table 1 Input voltage, levitation height, and frequency

Voltage [Vpp]	Height [μm]	Frequency [kHz]
2	18	11.7
6	48	11.4
8	46	10.3
10	38	10.0

4. Control signal

The electrical input signal response of the levitation mechanism is investigated. The input voltage and current, and their phase difference are measured with an FRA. The admittance curve at 6 V_{pp}, 8 V_{pp} and 10 V_{pp} is shown in figure 4. As the input voltage applied to the piezo increases, the peak of the admittance curve shifts to the lower frequency side. In addition, the magnitude of admittance slightly increases. Figure 4 shows similar trend compared with figure 3 which indicates the levitation height of the mechanism. The peak frequency of the levitation height and the peak frequency of the admittance shift to the low frequency side, as the input voltage increases. In our experimental results, the peak frequencies shown in figures 3 and 4 do not agree with each other, since the complex admittance is discussed. In future, the peak frequency of the admittance will be discussed by taking effective conductance into account.

The phase difference between input voltage and current is shown in figure 5. Since the piezo is capacitive load, the phase is almost 90 degrees through drive frequency except 11 kHz- 13 kHz. The phase curve shows drop between 11 kHz and 13 kHz. The depth of the valley changes according to the input voltage. The larger the input voltage is, the deeper the valley is. This shows the nonlinearity of the levitation mechanism and the similar trend with the levitation shown in figure 3.

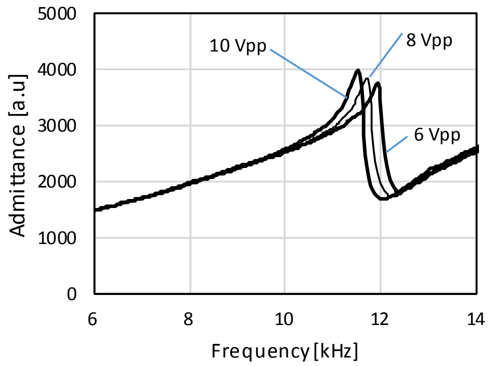

Figure 4. Admittance of the control signal.

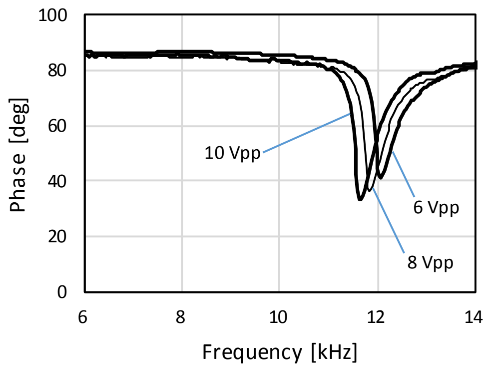

Figure 5. Phase of the control signal

5. Summary

The levitation characteristics of an actuator was discussed. The levitated object was the actuator itself. The levitation was caused by vertical vibration of a stacked-type piezoelectric actuator with a counter weight and a bottom plate. The vibration of the plate generated an air film underneath the plate. An AC voltage at an appropriate frequency caused the actuator to levitate. The vibration amplitude and frequency varied the thickness of the air film and the levitation height.

The levitation and the control signals were clarified experimentally. A levitation height was measured as a function of frequency. An input voltage and current applied to the piezo, and their phase difference were obtained. The levitation actuator indicated capacitive, since it comprised the piezo. However, it appeared resistive while the actuator was levitating.

We measured the levitation height, admittance, and phase difference. These results showed nonlinearity. In future, the complex admittance was taken into account, and the phenomenon is estimated without sensors.

This work was financially supported by the Japan Society for the Promotion of Science, Grant-in-Aid for Scientific Research (C), No. 26420212.

References

[1] Torii A, Mitsuyoshi Y, Mototani S and Doki K 2016 *Proc. of the 16th euspen Int. Conf.* Nottingham, UK P2.18

[2] Torii A, Sone S, Doki K and Mototani S 2015 *Proc. of the 15th euspen Int. Conf.* Leuven, Belgium P4.30

[3] Priya S, Viehland D, Carazo A V, Ryu J and Uchino K 2001 *J. of Appl. Phys.* **90**, 1469-1479