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Feedback control of a levitation actuator used in a non-contact mechatronic system

Akihiro Torii[1], Ayaka Nakazato[1], Suguru Mototani[1], Kae Doki[1]

[1]*Aichi Institute of Technology, 1247 Yachigusa, Yakusa-cho Toyota 470-0392 Japan*

torii@aitech.ac.jp

Abstract
In this paper, we describe a feedback control of a levitation actuator. The actuator is used in a non-contact mechatronic system, such as a desktop manufacturing system, an optical positioning stage, and other miniature systems. The levitation actuator consists of a stacked-type piezoelectric element (piezo), a flat plate, and a counter weight. The counter weight is attached at the top of the piezo, and the flat plate is at the bottom of the piezo. The vibration of the piezo causes the plate to vibrate vertically. The vibration of the plate generates an air film underneath the plate by Squeeze film effect, and the air film lifts the actuator. The counter weight which is heavier than the plate keeps its vertical position by the inertial law. We show the levitation of the levitation actuator, and a minute levitation realizes the non-contact condition. A feedback controller is implemented. A dead band is introduced to prevent hunting. The levitation height is controlled experimentally by tuning the drive frequency of the piezo. The experimental results verify that the developed feedback system is suitable for the control of the levitation actuator. The constant levitation is achieved.

Levitation, Actuator, Vibration, Micro robot, Control

1. Introduction

Small production systems which consist of miniature sensors and actuators are developed. Positioning stages play important roles in the production systems. Piezoelectric actuators (piezos) are used in small-scale precision positioning stages. An inchworm motor using three piezos and three electromagnets was developed [1]. Two excited electromagnets keep their positions by the electromagnetic forces and piezos push the non-excited electromagnet. The motion of the inchworm motor is affected by friction, since the electromagnets slide on a surface.

Non-contact manipulation is realized by an air film. An active air bearing using an air film generated by the ultrasonic oscillation of the piezo was reported [2]. The thickness of the air film of the bearing was controlled by PI feedback [3]. A three degrees-of-freedom inchworm using acoustic levitation was reported [4]. A levitation actuator was implemented so that the friction was eliminated. The electrical signal at an appropriate frequency was applied to the piezo, and the vibration of the piezo generated the air film which lifted the inchworm. A levitation characteristics of the levitation actuator using a piezo was described [5]. The amplitude of the drive voltage changed the drive frequency due to the nonlinear behaviour of the piezo. The importance of nonlinearity of the piezo was described [6].

In this paper, the vertical displacement of the levitation actuator is controlled by a feedback control. In order to avoid the nonlinearity of the piezo, the drive frequency is controlled, and the drive voltage is not changed. The structure of the levitation actuator, the levitation height, a feedback control system, and some experimental results are described.

2. Levitation actuator

2.1. Structure

A levitation actuator used in this paper is shown in Figure 1. It consists of a counter weight, a piezo, a circular plate, and semicircular metal hinges. They are fixed with screws. The counter weight, 40 g, is attached to the piezo. The plate is 3 cm in diameter, 3 mm in thick and 5 g in weight. The thickness and outer diameter of the semicircular metal hinges is 2 mm and 20 mm, respectively. 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. The squeeze film generated under the plate lifts the actuator which is placed on a flat plane.

The control signal is generated by a function generator, and is applied to the piezo through an amplifier. 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 counter weight is also measured.

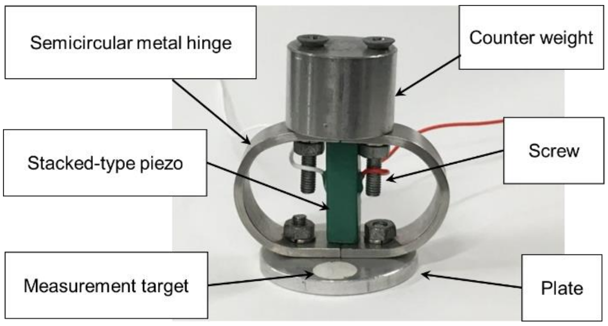

Figure 1. Levitation actuator which realizes non-contact condition

2.2. Levitation height

Figure 2 shows the vertical position of the plate and that of the counter weight. The waveform applied to the piezo is a 10 kHz and 10 V peak-to-peak (V_{pp}) sinusoidal with a 50 Vdc offset. The voltage is applied at 175 ms, and the actuator starts to levitate. The averaged vertical position of the plate is about 11 μm, which is determined as a levitation height. The averaged vertical position of the counter weight is about 17 μm. The difference, 6 μm, between them is generated by the DC offset voltage applied to the piezo.

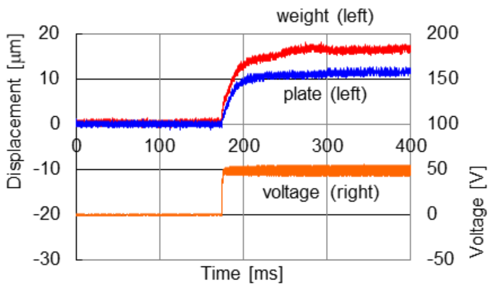

Figure 2. Levitation height and drive signal

3. Control system

The block diagram of the levitation height control is shown in Figure 3. An Arduino board is used to control the levitation height. One control period is 0.2 s including calculation time. The levitation height is processed by the averaging block, which is a low pass filter. The average height is compared with the reference height. The dead band block is implemented in order to avoid hunting of the levitation height. The proportional control gain K_p is used.

The levitation actuator is controlled by the drive frequency, f, which is determined by the input signal, u, of the function generator. The relation between the input voltage and the drive frequency of the function generator is shown in Figure 4. The frequency ranges linearly from 1.0 kHz to 11 kHz as a function of the input voltage from 0 V to 5 V.

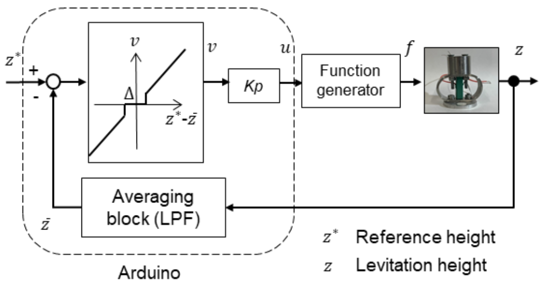

Figure 3. Block diagram of feedback levitation height control

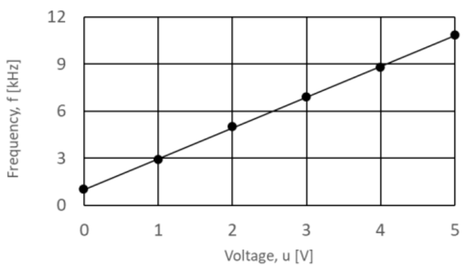

Figure 4. Drive frequency as a function of input to function generator

4. Experiment

The width Δ of the dead band is one of the most important parameters. Two dead bands are examined. First, a wide dead band is tested. The reference levitation height is 6 μm, and 6 μm dead band is used, i.e. the height is between 3 μm and 9 μm. Next, a narrow dead band is tested. The reference levitation height is also 6 μm, and 2.4 μm dead band is used, i.e. the height is between 4.8 μm and 7.2 μm. The proportional gain K_p is also important. First, the gain K_p=1 is used for the wide dead band. However, the system continuously overshoots and then undershoots, struggling to settle at the desired height. The gain K_p is gradually reduced, and the gain K_p=0.01 is used in the following experiments.

The initial drive frequency is 5.0 kHz, and the voltage applied to the piezo is 40 V_{pp}. Figure 5(a) shows the result obtained by the wide dead band, 6 μm. The levitation converges in the dead band in 2 s, exceeds 9 μm by a disturbance at 18 s, and returns in the band. Figure 5(b) shows the result obtained by the narrow dead band, 2.4 μm. As with the result using the wide dead band, the levitation height is in the reference height range. Figure 5(c) however shows the different result. Once the levitation height deviates from the target range by a disturbance, the oscillation phenomenon is caused by the narrow dead band, and the height does not settle the desired height. A gain K_p and a narrow dead band of the control system cause the hunting. Frequency characteristics of the levitation actuator and control period of the system are additional factors. The addition of damping will slow system response.

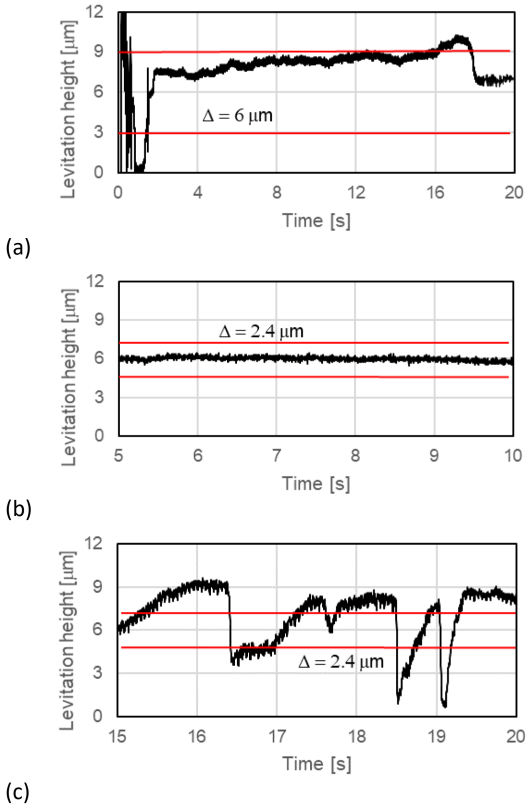

Figure 5. Measured levitation height with dead band of (a) 6 μm, (b) 2.4 μm stable, and (c) 2.4 μm unstable

5. Summary

The levitation height of the levitation actuator was measured. A feedback control of the levitation height was implemented. The drive frequency of the piezo could change the levitation height. By the use of a feedback control with a wide dead band, the levitation height was controlled. However, the control with a narrow dead band caused hunting phenomena. In future, we will tune the control parameters, for example proportional gain K_p, the width Δ of dead band, and control period experimentally.

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