Friction Control Using Ultrasonic Vibration for Piezoelectric Translation Apparatus

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Abstract

We propose friction control using vibration for piezoelectric translation apparatus. The apparatus is an inchworm-type microactuator using piezos. By the use of vibration of the piezo, we can control a friction force which is a clamping force of the inchworm-type microactuator. The microactuator consists of push-pull piezos and a friction control piezo. The push-pull piezos deform in the horizontal direction. The horizontal piezos are operated by a trapezoidal waveform at about 1 Hz which is much smaller than the vibration frequency of the friction control piezo. The friction control piezo, which vibrates in the vertical direction intermittently, is operated by sinusoidal waveform at about 4.3 kHz. The vertical vibration of the piezo reduces the friction force between the element and operating surface. Experimental results show that the control sequence of the microactuator determines the moving direction of the proposed piezo translation apparatus.

1 Introduction

An inchworm-type microactuator utilizing the inverse piezoelectric effect is one of the most useful actuators which generate accurate large-stroke motion. The piezoelectric element (piezo) features fast response times, high power density, and submicron accuracy. The inchworm-type piezo microactuator demonstrates large stroke and reasonable speeds.

We previously developed a microactuator based on the principle of an inchworm which consists of electromagnets for clamping and piezos for thrusting [1]. Since the microactuator uses the electromagnets and the piezos, we have to prepare a high current energy source for the electromagnets and a high voltage energy source for the piezos. We therefore developed microactuators which do not use the electromagnets [2, 3]. The microactuator without the electromagnets kept its position by a friction force caused by its weight. The presence of the friction force, however, sometimes interferes with the motion of the microactuator.

In this paper, a friction cotrol using vibration for an inchworm-type piezoelectric translation apparatus is proposed. The apparatus is the inchworm-type microactuator driven by the deformation of piezos, and this microactuator can be utilized in XY positioning systems. Preliminary experimental results are demonstrated.

2 Design and principle

Figure 1 shows the photographs of the proposed microactuator, which weighs 87 g. Three weights are glued in series with two piezos. The piezos in the horizontal direction push and pull the weights. The length of the piezo is 10 mm, and it extends the length by 9.1 μm at 150 V.

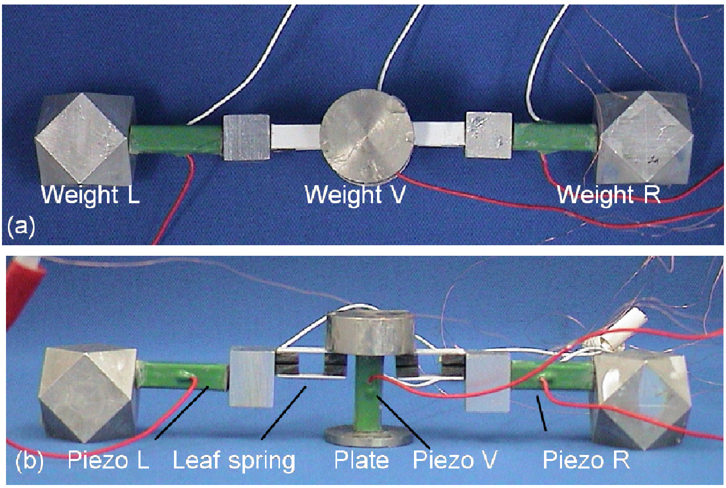

Figure 1: Design of the proposed microactuator. (a) Top view and (b) side view.

A friction control element consists of Weight V, Plate, and Piezo V, which vibrates vertically. The friction force at Weight R and Weight L is constant, since the friction force is determined by their weight. The friction force at Plate, however, can be reduced by the vibration of Piezo V.

Two parallel leaf springs are inserted between Piezo R and Piezo L. The parallel leaf springs have two important roles. One is vibration isolation. The leaf springs can cut off the vertical vibration caused by Piezo V. The other is alignment-free design of the microactuator. The leaf spring allows minute misalignment of piezo length, although highly accurate alignment is required in link mechanism

The principle of the proposed microactuator is shown in Figure 2(a). The microactuator moves rightward by repeating the following cycle. The initial situation is indicated in Figure 2(a)(1). First, Piezo R expands as shown in Figure 2(a)(2). Since the sum of the friction force at Plate and at Weight L is larger than that at Weight R, Weight R moves rightward. Figure 2(a)(3) is the most important period of the principle. While Piezo V vibrates and Plate levitates, Weight V is pulled by Piezo R and is pushed by Piezo L, and then the friction control element moves rightward. Then Piezo L returns to its original length and drags Weight L.

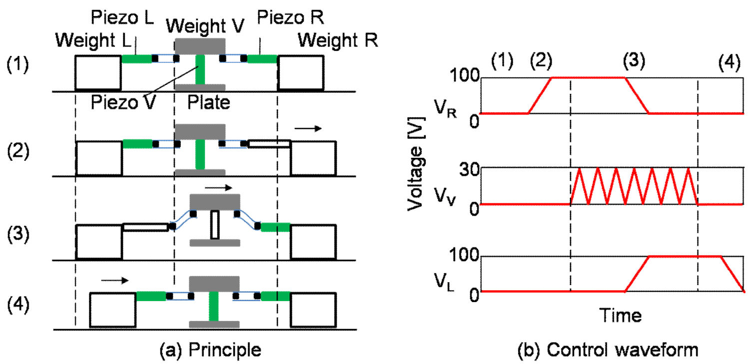

Figure 2: (a) Principle of operation and (b) control voltage applied to piezos.

Figure 2(b) shows a schematic diagram of control waveforms. The voltages V_R, V_L and V_v denote the applied voltage to Piezo R, L, V, respectively. The maximum voltage to Piezo R and L is 100 V. The voltage applied to Piezo V is a sinusoidal waveform, with the amplitude of 30 $V_{p\text{-}p}$ and the frequency of 4.3 kHz. The vibrating frequency is determined by preliminary experiment. The control frequency is 1 Hz.

3 Experimental results

We operated the proposed microactuator righward and leftward. Figure 3 shows experimental results. The horizontal displacement of Weight R and L is measured by displacement sensors. The displacement in the right direction is expressed as positive value. While the gate signal is high level, Piezo V vibrates and the friction control element levitates. The microactuator goes rightward in Figure 3(a), and leftward in Figure 3(b). As indicated with lead lines, Weight R and L move before and after the vertical vibration of Piezo V, which is expressed by the high level of the gate signal. The microactuator shifts 2-7 μm per one cycle in both directions. While the gate signals are high level, both weights are stationary. The levitation height of the Plate was about 2 μm measured by an displacement sensors.

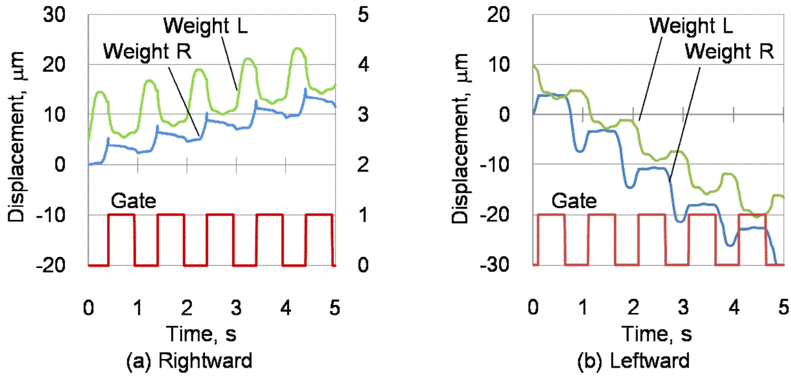

Figure 3: Displacement (a) rightward and (b) leftward

5 Summary

This paper described the linear displacement of the microactuator using a friction control mechanism. The developed microactuator consisted of a piezo vibrating in the vertical direction and push-pull piezos deforming in the horizontal direction. After showing the operation principle, we demonstrated the linear displacement of the proposed microactuator. The displacement per one cycle is 2-7 μm.

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