euspen's 21st International Conference & Exhibition, Copenhagen, DK, June 2021
www.euspen.eu

The evaluation of a miniature robot using electromagnetic force

Akihiro Torii[1], Hiroaki Miyake[1], Suguru Mototani[1], Kae Doki[1]

[1]*Aichi Institute of Technology, Japan*

torii@aitech.ac.jp

Abstract
The performance of an inchworm type miniature robot is evaluated in this paper. The robot, which is operated on an iron surface, consists of delta-connected multi-layered piezoelectric materials (piezos) and electromagnets attached at the vertices. One non-excited electromagnet moves by the deformation of the piezos while two excited electromagnets hold positions. Three electromagnets move sequentially, and the linear and rotational displacements are realized by the principle of an inchworm. The piezos extend and contract horizontally, and the robot moves in a horizontal xy plane. The attractive force of the electromagnets works vertically in the z direction. Therefore, the electromagnetic force affects the performance of the robot. While a piezo extend about 17 μm horizontally, a non-excited electromagnet moves about 15 μm and an excited electromagnet moves several microns in the reverse direction. The non-excited electromagnet also moves several microns in the vertical displacement, which is not suitable for the precise displacement of the robot.

miniature robot, electromagnet, piezoelectric element, precision positioning

1. Introduction

Small production systems which consist of miniature sensors and actuators are developed. A multi-axis positioning system is essential to ensure desktop manufacturing which enables savings in energy and space. Positioning stages play important roles in the production systems. Piezoelectric actuators (piezos) are used in small-scale precision positioning stages. A three degree-of-freedom (3-DOF) inchworm which obtains submicron accuracy along unlimited working range is developed [1]. The inchworm consists of piezos and electromagnets. The non-excited electromagnets sequentially move by the deformation of the piezos, and the inchworm realizes linear and rotational displacement on a plain surface.

The motion of the inchworm is affected by friction, since the electromagnets slide on the surface [2]. The attractive force of the electromagnet works vertically in the z direction. The electromagnetic force, therefore, affects the performance of the robot. In principle, an excited electromagnet keeps position and a non-excited electromagnet moves. There is a possibility that the strong electromagnetic force changes the vertical position of the electromagnet. The large electromagnetic force may cause the variation of the displacement of the non-excited electromagnet.

In this paper, the performance of an inchworm type miniature robot is evaluated. The vertical and horizontal displacements of the electromagnets are measured. After the structure of the miniature robot is described, the simplified structure is introduced. Next, experimental methods are explained. Then, some experimental results are shown. Finally, the performance of the inchworm type miniature robot is evaluated and future works are described.

2. Miniature robot

A 3-DOF inchworm motor using piezos and electromagnets was developed [1]. Figure 1 shows the inchworm consists of three stacked piezos (NEC-Tokin, AD050516) and three electromagnets. An equilateral triangle is formed with three piezos which extend and contract horizontally. The piezos are 20 mm long, and the cross section is 5 mm x 5 mm. They extend 17.4 μm by the applied voltage of 150 V_{DC}. Electromagnets are attached to the vertices of the triangle. They are fixed with adhesives. The electromagnetic force generated by the electromagnet is about 5 N at 10 V_{DC}. One electromagnet is not excited, and the others are excited. The non-excited electromagnet moves by the deformation of two connected piezos. After one electromagnet moves, another electromagnet is free and moves. Two excited electromagnets keep their positions by the electromagnetic forces and piezos push the non-excited electromagnet. The control signals are generated by a computer and applied to the piezos and electromagnets through amplifiers. One control cycle is 1 s.

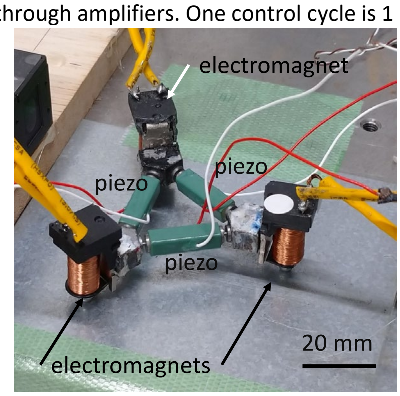


Figure 1. A 3-DOF inchworm using piezos and electromagnets.

3. Experiment

A simplified experimental model is introduced. Figure 2 shows the schematic diagram of the model. Two electromagnets are attached at the ends of the piezo. The vertical (z-) and horizontal (x-) position of the electromagnet are measured with displacement sensors (KEYENCE, LK-G5000 series).

First, the z-position of the excited electromagnet is measured. While the piezo is not operated and it keeps its original length, one electromagnet is excited. The vertical position change of the excited electromagnet is measured. Next, the horizontal piezo is driven by rectangle and sinusoidal signal, while one electromagnet is excited by 10 V_{DC}. The amplitude applied to the piezo is 150 V, and the drive frequency is 1 Hz in order to prevent an inertial force. The x- and z-positions of the excited electromagnet are measured. The positions of the non-excited electromagnets are also measured.

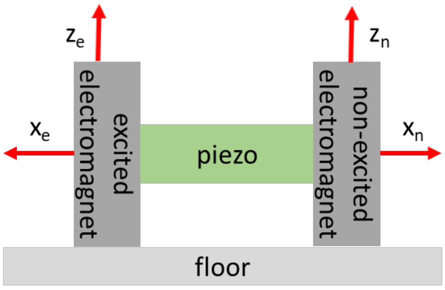


Figure 2. A simplified experimental model.

4. Results

Figure 3 shows the experimental result in z-displacement. Due to the limitation of the system, it contains a lot of noise. When the voltage was applied to the electromagnet at about 0.5 s, it moved -0.25 μm in the vertical direction.

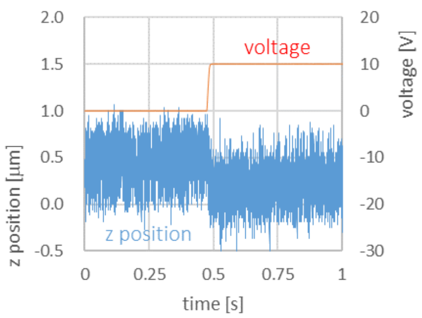
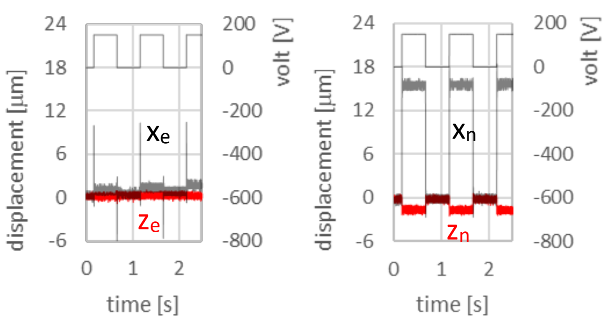


Figure 3. Vertical displacement of electromagnet.

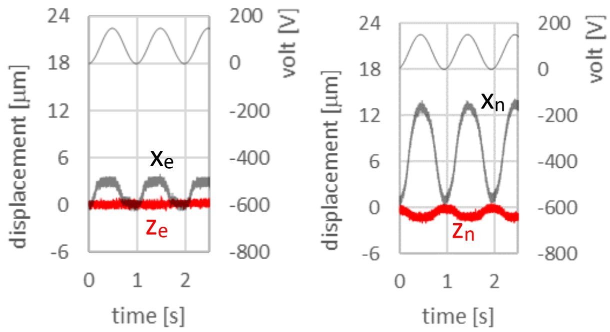
Figure 4 shows the displacement obtained by a rectangular voltage applied to the piezo, while one electromagnet is excited by 10 V_{DC}. In Figure 4(a), the excited electromagnet moved about 1 μm in x-direction, and the spike was shown. The z-displacement cannot be observed. In Figure 4(b), the amplitude of the x-displacement of non-excited electromagnet is about 15 μm.



(a) excited electromagnet (b) non-excited electromagnet

Figure 4. z- and x-displacement with rectangular waveform.

Figure 5 shows the displacement obtained by a sinusoidal voltage applied to the piezo, while one electromagnet is excited by 10 V_{DC}. In Figure 5(a), the excited electromagnet moved about 3 μm in x-direction. The vertical displacement cannot be observed. In Figure 5(b), the non-excited electromagnet moves both in x- and z-direction. The amplitude of the x-displacement is about 13 μm.



(a) excited electromagnet (b) non-excited electromagnet

Figure 5. z- and x-displacement with sinusoidal waveform.

5. Discussion

The large noise is observed in Figure 3. The cause of the noise is the use of wires for the drive of the electromagnets and piezos. The wires will be replaced with thinner ones in order to eliminate the disturbance noise in the future.

In Figures 4 and 5, the sum of the horizontal displacement of the excited electromagnet and that of the non-excited electromagnet roughly agreed with the extension of the piezo. The problem is the z-displacement, about - 2 μm, of the non-excited electromagnet. The vertical displacement of the non-excited piezo is synchronized with the horizontal extension of the piezo, and is much larger than that of the excited electromagnet. The root cause of the z-displacement is a convex shape of the contact point of the electromagnets. The convex shape of the excited electromagnet causes the tilt motion of the inchworm and enlarges the z-displacement of the non-excited electromagnet by the leverage principle. Although the z-displacement of the non-excited electromagnet is parasitic displacement, it should be reduced to improve the performance of the inchworm. The flatness of the contact point of the electromagnet according to the z-displacement will be investigated in the future.

6. Summary

This paper described the displacement of the electromagnet of the inchworm. The horizontal displacement of the electromagnets of the simplified model was measured. The vertical displacement of the excited electromagnet was smaller than 0.3 μm. The horizontal displacement of the non-excited electromagnet depended on the extension of the horizontal piezo displacement. The vertical displacement of the non-excited electromagnet was much larger than that of the excited electromagnet. Although the direction of the electromagnetic force was orthogonal to the extension direction of the piezo, the horizontal extension of the piezo caused parasitic vertical displacement of the non-excited electromagnet. In future works, the shape of the contact point is investigated. The horizontal linear and rotational displacement relative to the vertical electromagnetic force is taken into consideration.

References

[1] Torii A, Mitsuyoshi Y, Mototani S, Doki K, 2016, the 16th euspen int. conf., Nottingham, UK, P2.18

[2] Torii A, Takaki Y, Mototani S, Doki K, 2018, the 18th euspen int. conf., Venice, Itary, P3.05, 203-204