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Structure and control of an inchworm for precise displacement

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Abstract
An inchworm used in a small production system is described in this paper. The inchworm consists of electromagnets for keeping its position and stacked-type piezoelectric actuators (piezos) for moving. The inchworm repeats the excitation of the electromagnets and the horizontal extension of the piezos, and realizes a micron order precise displacement. The friction force acting on the electromagnets affects the motion of the inchworm since the electromagnets touch a moving surface. The vertical height of the point where the piezo pushes the electromagnet changes friction which holds the position of the inchworm. The control signal applied to the piezo causes an inertial force, i.e. the extension and contraction of the piezo generate an inertial force. The position of the inchworm is measured by changing the height of the horizontal piezo. The experimental results revealed the following points. (I) The high position of the piezo, 20 mm, realizes precise motion and small parasitic drift is observed. Parasitic drift is smaller than other structures. (II) The low position of the piezo, 6 mm, causes large displacement and several micron drift of the inchworm occurs when the piezo deforms. In summary, to realize precise displacement of the inchworm, the 20 mm high mounting position of the piezo is suitable for the inchworm under the experimental conditions.

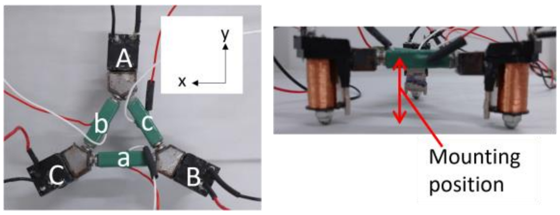
Inchworm, piezoelectric actuator (piezo), electromagnet, displacement, structure

1. Introduction

Although industrial products and electrical appliances have tended to become smaller, manufacturing equipment generally remains large scale systems. Small production systems and small positioning devices contribute to save the space consumption of the manufacturing equipment. Micro mobile inchworms consisting of piezoelectric actuators (piezos) and electromagnets have been developed [1, 2]. They do not have any guide mechanisms and they can realize minute displacement with three degrees-of-freedom (DOF), although commercial inchworm modues with nanometer accuracies is single-axes and consists of guide components. Therefore, there is a fluctuation in the displacement of one cycle of the inchworm. The reason is related to the stability of the position of the excited electromagnet, which occurs during deformation of the piezo. In order to realize precise motion, the positioning of the electromagnets are important. In this study, the mounting position of the piezo is changed and the relationship between the structure and the displacement of the inchworm is clarified.

2. Inchworm and experiment

Figure 1 shows the picture of the inchworm. Figure 1(a) shows a top view of the inchworm. The inchworm has three piezos consisting the sides of a triangle and electromagnets attached to a connection point of the piezos. Three electromagnets denoted A, B C, and three piezos denoted a, b, c are used. The electromagnet with yoke is in contact with a metal floor. The piezo used is AE0505D16DF manufactured by NEC Tokin Co., and extends 17.4 µm with respect to an applied voltage of 150 V DC. The inchworm is 75 mm wide, 70 mm long, and 75 g weight. The electromagnets and piezos are driven with thin wires. Figure 1(b) shows a side view of the inchworm. The mounting position of the piezo affects the performance of the inchworm.



(a) top view (b) side view

Figure 1. Photo of inchworm

The control signals used to move the inchworm in the Y direction are shown in Figure 2. The signals are generated by a function generator, Arduino, and amplifier. A 150 V square wave is applied to the piezos, and a 10 V square wave is applied to the electromagnets. The performance of the electromagnets are important for positioning. However, it is not discussed in this paper. One of three electromagnets are not excited, and sequentially moves by the deformation of the piezos. Figure 3 shows the measurement method. For the measurement of the displacement of the inchworm, laser displacement meters (Keyence, LK-G3000 series, 0.05% of full scale linearity) are used. The position of the inchworm is defined as the position of the electromagnet A in XY coordinate. The displacement in the Y and X directions for one cycle is measured continuously.

The structure of the inchworm is changed, i.e. the height of the mounting position of the piezo shown in Figure 1(b) is varied. The mounting positions of the piezo from the metal floor are 6 mm, 10 mm, and 20 mm.

3. Experimental results

Figure 4(a) shows the displacement of the inchworm when the piezo is mounted at 6 mm height. The inchworm realizes

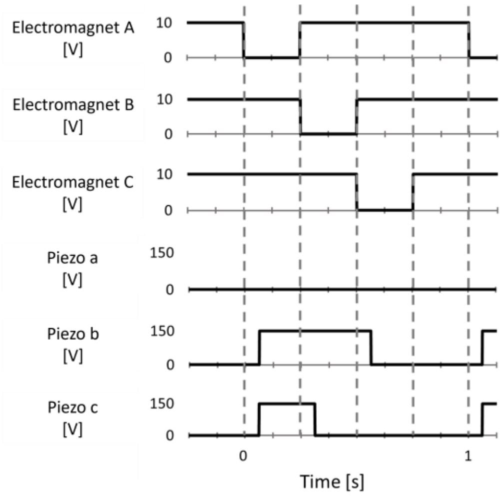


Figure 2. Control signals

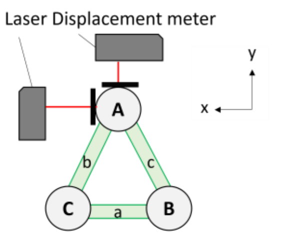


Figure 3. Measurement method using a laser displacement meter

incremental displacement about 210 μm in Y direction and 50 μm in X direction for 10 s. Although the control signal for Y displacement is used, a parasitic X displacement occurs. The parasitic displacement is caused by the tension of the power wires. The spike is shown in the position measurement. Since the piezo is mounted at the low position, the electromagnet moves according to the deformation of the piezos. While the electromagnet moves, the wire pulls or pushes the electromagnet by its stiffness. Figure 4(b) shows the displacement of the inchworm with the piezo position of 20 mm height. The displacement of the inchworm is about 180 μm in Y direction and 10 μm in X direction for 10 s. In this case, the piezo mounted at the high position causes a bending moment at the contact point of the floor, so that the small parasitic displacement occurs.

Figure 5 shows the plot of the displacement in XY coordinates. Horizontal axis and vertical axis denote x- and y- displacement, respectively. They are expressed by different magnification. The displacement for one cycle is plotted while the inchworm moves for 30 cycles. The displacement of the inchworm with low mounted piezo, 6 mm, is larger than that of other inchworms. Although the Y-displacement control signal is applied to the inchworm, it moves in not only Y-direction but X-direction. This is caused by the stiffness of control wire. Table 1 shows the average amount of displacement per cycle for each mounting position of the piezo. The displacement in the X and Y direction per cycle decreases as the mounting position increases.

4. Summary

In this paper, the mounting height of the piezoelectric element of the inchworm was changed. The heigher the piezo position was, the smaller the inchworm displacement was. The result is helpful to improve the performance of the inchworm. In future, an optimal mounting position of the piezoelectric element is determined and electromagnets playing important roles for positioning are improved. A wireless inchworm carrying control curcuits and batteries is also being developed to eliminate wire problems. This work was supported by JSPS KAKENHI Grant Number 21K03972.

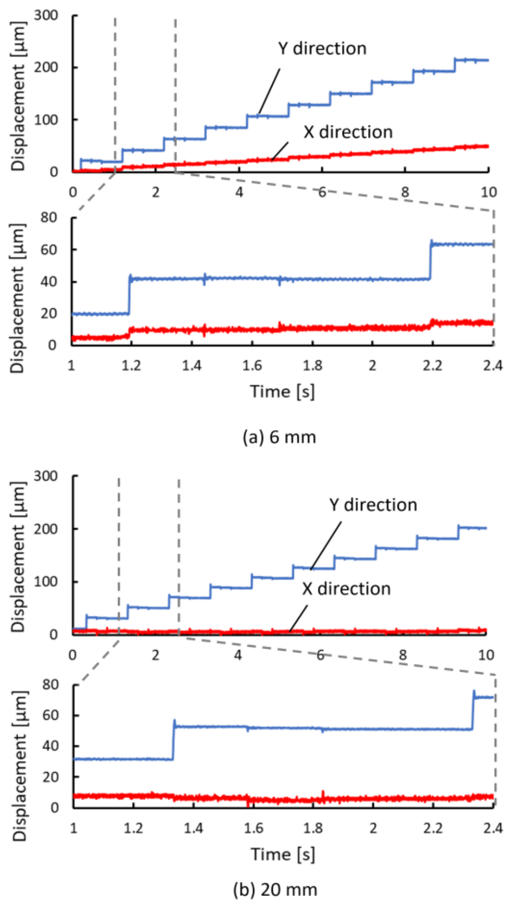


Figure 4. Displacement of inchworm

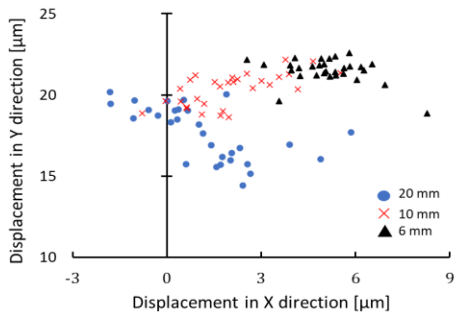


Figure 5. Plot of the displacement of inchworm per one cycle.

Table 1. Displacement of inchworm per one control cycle

Mounting position of the piezo	Displacement in Y direction	Displacement in X direction
6 mm	21.5 μm ± 0.8 μm	5.1 μm ± 1.1 μm
10 mm	20.3 μm ± 1.0 μm	2.0 μm ± 1.5 μm
20 mm	17.7 μm ± 1.7 μm	1.2 μm ± 1.7 μm

References

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