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Design of a 3D-Printed Linear Positioner with Micrometer Resolution

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Abstract **-** This paper proposes a 3D-printed micro-positioner actuated by piezoelectric elements. The lever-based amplifying mechanism and flexure hinge mechanisms are fabricated by a commercial 3D printer. Large step response, step-train response and sinusoidal response are presented to show the performance of the proposed system. Experimental results demonstrate 100 micrometer stroke with 1 micrometer resolution. Moreover, this micro-positioner is capable of tracking sinusoidal motion. Using 3D-printing technique, micro-positioners can be further optimized iteratively and cost-effectively.

Keywords**:** 3D-printing, precision positioning, flexure hinge, piezoelectricity, mechatronics

1. Introduction

The needs of precision positioning increase in many kinds of fields, such as measurement and manufacturing. Therefore, precision positioners are often equipped in the systems. In the fields of scanning tunneling microscopy [1, 2] and atomic force microscope [3, 4], high-precision positioning will be significantly important.

Recently, electromagnetic actuators [5] and piezoelectric actuators [6] are two of the most common ways for precision positioning systems. Piezoelectric actuators have numbers of advantages, such as small size, less weight, fast response, high clamping force, etc. These aforementioned have made piezoelectric actuators extremely valuable for applications in precision positioning. Nevertheless, hysteresis phenomenon and short traveling range become an issue.

Cooperating flexure hinge mechanism with the actuator becomes popular these days. Smoothly continuous motion and no backlash are the advantages of flexure hinge mechanism, which lead to a better performance for moving stages. However, most of the flexure hinge mechanisms are manufactured by electrical discharge machining (EDM) [7]. EDM process often consume lots of effort and budget. Utilizing 3D-printing [8, 9] with polyactic acid (PLA) material not only reduces the cost of manufacturing process, but also makes it easier to implement and customize.

With the pros and cons mentioned, a 3D-printed flexure hinge positioner cooperating with piezoelectric actuators is presented in this paper. This positioning system has 100 micrometer translational stroke with 1 micrometer resolution. Furthermore, we present some experimental results to show the satisfactory performance.

2. System Design

Due to the development of 3D-printing technique, we can now easily fabricate or customize lots of complicated mechanisms. Fig. 1(a) shows the experimental setup, includes piezoelectric actuators, a 3D-printed moving stage, and a laser displacement sensor.

Piezoelectric elements (AE0505D16F, THORLABS) act as the actuator of the proposed system. For measuring the displacement of the moving stage, a laser displacement sensor (LK-H020, KEYENCE) [10] is fixed facing at the end of the moving stage. Referencing to Physik Instrumente's product P-780 [11], which considered to be a compact and well design, Fig. 1 (b) shows the detailed design of the proposed moving stage. Lever rule is utilized to amplify the displacement of the moving stage, and the width w is designed to 1 mm so that the flexure hinge mechanism can work efficiently. The moving stage thickness t is 10 mm. With the flexure hinge design, the displacement will be much smoother in y direction.

With the hysteresis phenomenon, an appropriate feedback control scheme is necessary to achieve high precision positioning. Proportional-Integral-Derivative (PID) controller, which is a classic controller, has a simple scheme and can be easily implemented in plenty of systems. Due to the advantage, a PI closed-loop controller is applied to deal with the nonlinear disturbance. Moreover, the whole positioning system is fixed on an optical table so that the vibration of external environment can be eliminated.

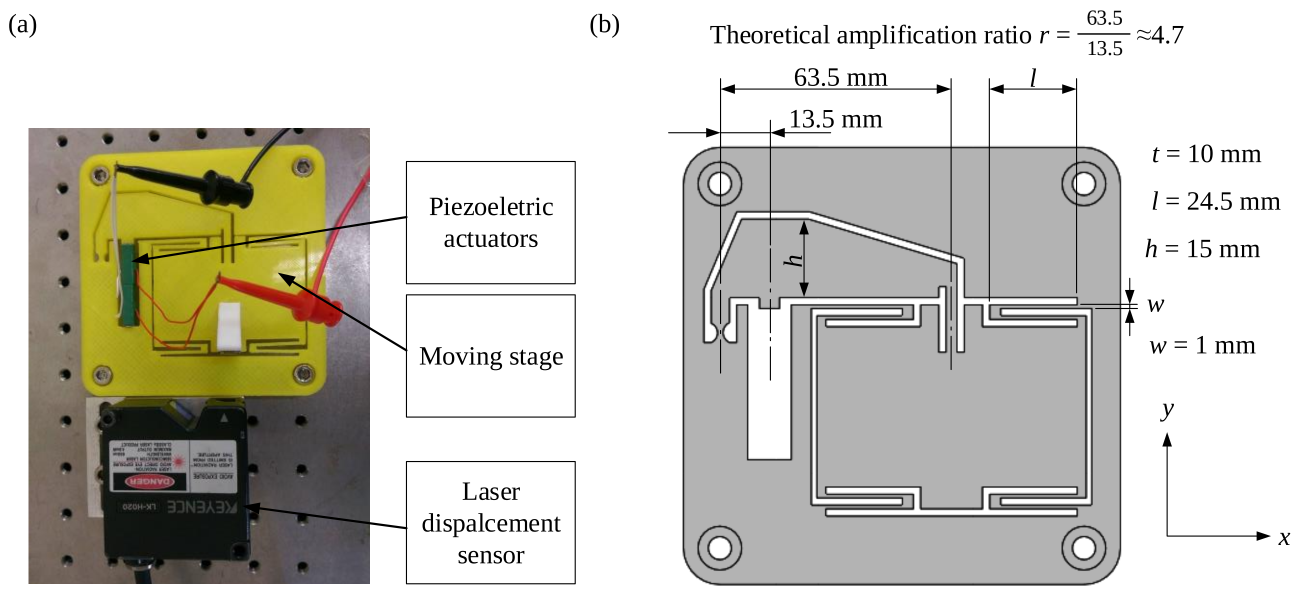

Fig. 1: (a) Experimental setup and (b) the detailed design of the moving stage.

Fig. 2 shows the block diagram of the designed system. The piezoelectric actuator chosen has a maximum displacement of 17.4 μm, and generates 850N clamping force. To integrate the system, National Instrument USB-6221 Data Acquisition (DAQ) is selected. The laser displacement sensor measures the displacement of the moving stage and feeds back the measurement results to DAQ.

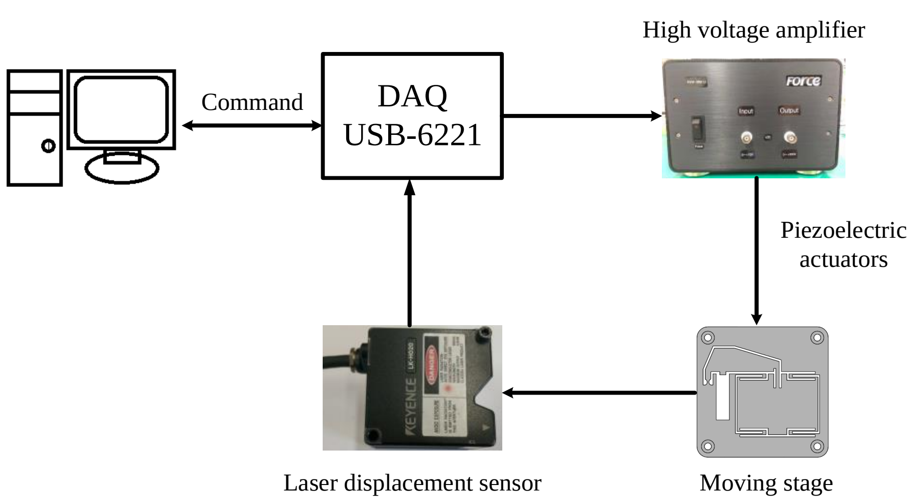

Fig. 2: The block diagram of the proposed system.

3. Experimental Result

3.1. Large Step Response

Fig. 3(a) and Fig. 3(b) are the large step response results of the system, with a step of 50 μm and 100 μm respectively. The full stroke of the proposed design can reach to 100 μm. We can observe that the overshoot is about 3% with 0.3 % steady-state error, and the rise time and settling time are 0.1 second and 0.6 second respectively.

3.2. Step-Train Response

In the field of precision positioning, step-train motion is one of the most common operations. We can also find out the resolution of the moving stage by the results of step-train response experiments. Fig. 4 shows the result of step-train response with each step equal to 1 μm.

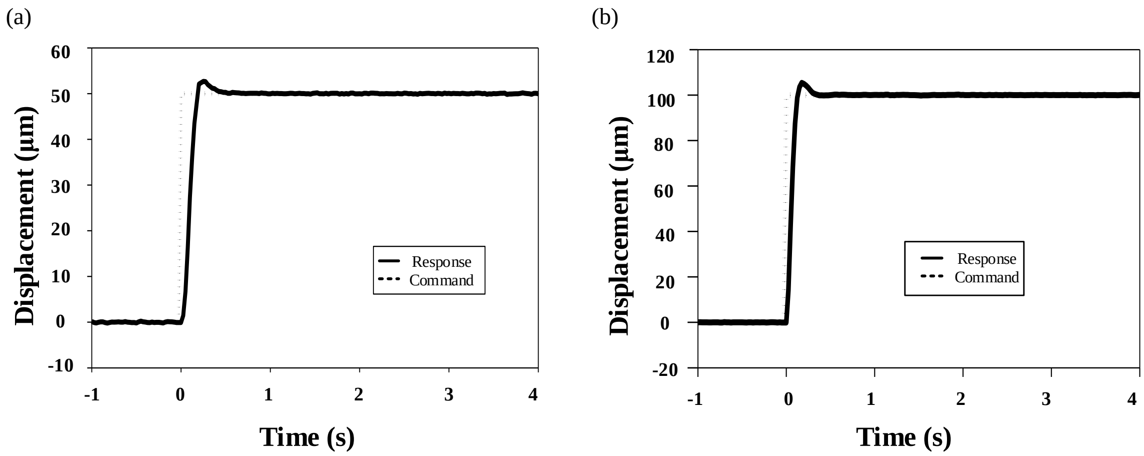

Fig. 3: Large step responses with a step of (a) 50 μm and (b) 100 μm.

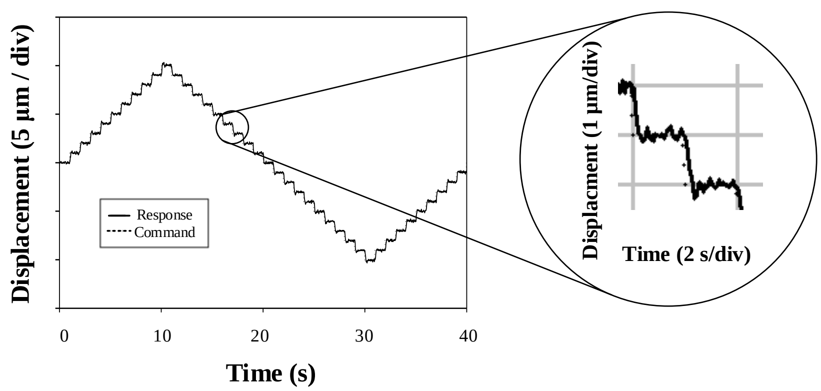

Fig. 4: Step train responses with 1 μm each step.

3.3. Sinusoidal Response

To test the dynamic motion and tracking capability of the proposed system, we made some sinusoidal response experiments. Experimental results are presented in different frequencies and amplitudes. Experimental results with amplitudes of 10 μm and 50 μm at the frequency equal to 0.1 Hz and 0.5 Hz are shown in Fig. 5 and Fig. 6 respectively. As the frequency exceed 1 Hz, the performance of the proposed system gets unsatisfactory.

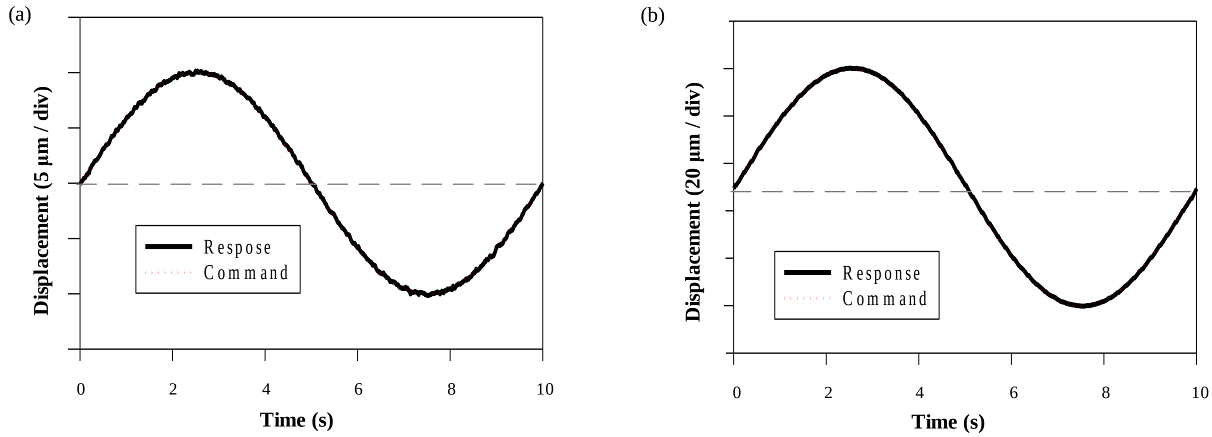

Fig. 5: Sinusoidal response at 0.1 Hz with amplitude of (a) 10 µm and (b) 50 µm.

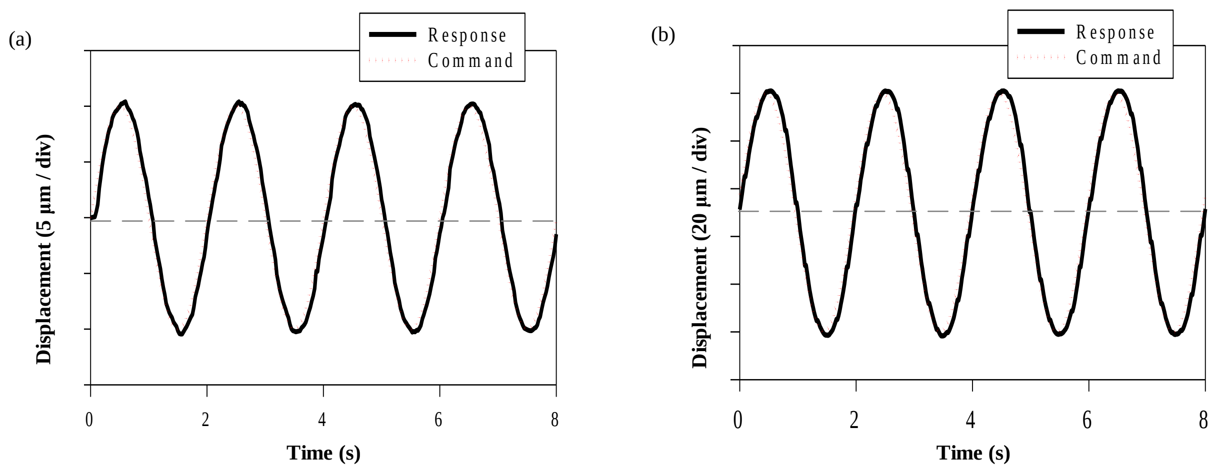

Fig. 6: Sinusoidal response at 0.5 Hz with amplitude of (a) 10 µm and (b) 50 µm.

4. Conclusion

With the growth of 3D-printing technique, manufacturing and customizing positioning system can be more efficient and cost less. In this paper, a novel method of fabricating positioner is presented. Having 100 µm traveling range and 1 µm resolution, the proposed positioner has the ability to track sinusoidal motion. In the future, the positioner can be improved iteratively and the control scheme will be enhanced. With the advanced design, next generation 3D-printed positioner will have better dynamical performance.

Acknowledgements

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