A new self-guided displacement-amplification flexure mechanism for a millimeter-range motion in a nano-positioning stage

Jung-Jae Kim[1], Young-Man Choi[1], Dahoon Ahn[1], Moon G. Lee[2] and Jaehwa Jeong[3,#]

1 Department of Mechanical Engineering, KAIST, 335 Gwahak-ro(373-1 Guseong-dong), Yuseong-gu, Daejeon, South Korea, 234-567
2 Department of Mechanical Engineering, Ajou University, Woncheon-dong, Suwon, South Korea, 443-749
3 Department of Control and Instrumentation Engineering, Korea University, 208 Seochang-ri, Jochiwon-eup, Youngi-gun, Chungnam, South Korea, 339-700
Corresponding Author / E-mail: jaehwa@korea.ac.kr, TEL: +82-41-860-1765, FAX: +82-41-865-1820

KEYWORDS : Flexure mechanism, nano-positioning stage, displacement-amplification, piezo-actuator

Flexure-based piezo-actuated nano-positioning stages are widely used as nano-positioning systems because they have several advantages including high resolution, fast dynamics, compact size, and simple mechanical structure. One of major drawbacks of flexure-based piezo-actuating stage is small range of motion. To overcome this drawback, most conventional flexure-based nano-positioning stages use serial combinations of motion guide and displacement-amplification mechanisms. However their serial combinations make the size of the stage large and limit small scale applications.

In this paper, a new self-guided displacement-amplification flexure mechanism for a millimeter-range motion in a nano-positioning stage is proposed. The proposed self-guided displacement-amplification mechanism enabling a large range of motion and a compact stage size has a skewed double-compound parallelogram structure that functions as both a motion guide and a displacement-amplification. The proposed mechanism contributes to increasing volume efficiency, which is a performance index defined as the product of travel range and resonant frequency per unit volume of the stage. The prototype stage was manufactured and its performances were evaluated.

Manuscript received: January XX, 2011 / Accepted: January XX, 2011

1. Introduction

Nano-positioning systems are essential in many areas including scanning probe microscopes, nano-manipulation, and photolithography equipments. Flexure-based piezo-actuated nano-positioning stages are widely used as nano-positioning systems because they have several advantages including high resolution, fast dynamics, compact size, and simple mechanical structure. One of major drawbacks of flexure-based piezo-actuating stage is small range of motion. To overcome this drawback, most conventional flexure-based nano-positioning stages use serial combinations of motion guide and displacement-amplification mechanisms [1]. However their serial combinations make the size of the stage large and limit small scale applications such as nano-manipulation, micro-coordinate measuring machine (CMM), and micro-factory.

In this paper, we propose a self-guided displacement-amplification mechanism eliminating a serial combination of a motion guide and a displacement-amplification mechanism. The proposed self-guided displacement-amplification mechanism enabling a large range of motion and a compact stage size has a skewed double-compound parallelogram structure that functions as both a motion guide and a displacement-amplification. Its structural symmetry improves positioning accuracy by reducing parasitic motion error and thermal deformation. The proposed mechanism contribute to increasing volume efficiency, which is a performance index defined as the product of travel range and resonant frequency per unit volume of the stage. A millimeter-range piezo-actuated nano-positioning stage has been implemented to verify the effectiveness of the self-guided displacement-amplification mechanism. In terms of volume efficiency, the stage was designed through design optimization frameworks to obtain the highest resonant frequency under constraints of a predetermined range, stress, and size limitation. The design results were verified using the manufactured nano-positioning stage, and closed-loop control performances were evaluated.

2. Self-guided displacement-amplification flexure mechanism

The proposed mechanism has a similar structure to a double-compound guide mechanism except the inclination of links and the location of input displacement. A schematic diagram of the self-guided displacement-amplification mechanism is shown in Fig. 1. Both mechanisms have only one degree-of-freedom (DOF). Four inclined links in the upper half forms a bridge-type displacement amplification mechanism while the other four links in the lower half form another one. The horizontal input displacement x_i of the piezo-actuator, one-half of which is acting on the left body and the other half on the right body, is amplified by two bridge-type displacement amplification mechanisms and transferred to the output displacement x_o of the moving body.

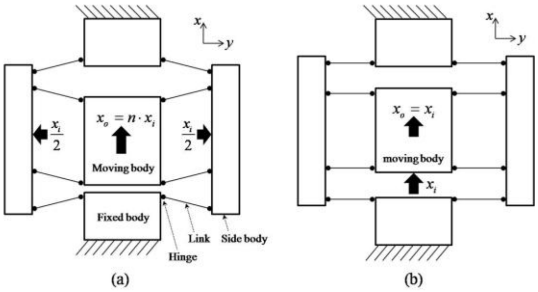

Fig. 1 Conceptual schematics: (a) proposed self-guided displacement-amplification mechanism and (b) conventional double-compound guide mechanism.

3. Prototype and experimental results

A millimeter-range piezo-actuated nano-positioning stage has been implemented using the self-guided displacement-amplification mechanism. The stage was designed through design optimization frameworks to obtain the highest resonant frequency under the constraints of a predetermined travel range, stress, and size limitation. The higher first resonant frequency is necessary to have higher control bandwidth which leads to higher positioning accuracy and better disturbance rejection. The size of the mechanism, except the base frame, was 98 mm × 56 mm × 15 mm, and the total size of the stage was 120 mm × 120 mm × 15 mm. Figure 3 shows the output displacement when input voltage was applied from 0 to 150 V. The maximum displacement was 963 μm.

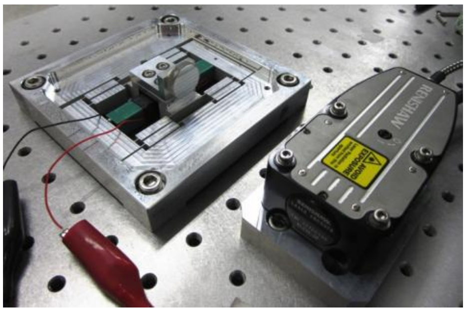

Fig.2 The manufactured nano-positioning stage

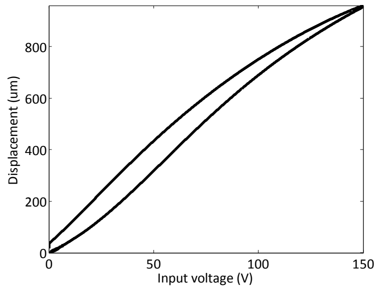

Fig.3 Displacement when input voltage was applied from 0 to 150 V

To validate the effectiveness of the proposed stage, we compared its performance with the performance of other similar-sized stages that have been developed so far [2-3]. From the viewpoint of a mechanism designer, we propose a simple performance index representing performance of a nano-positioning stage, volume efficiency, which is defined as the product of travel range and resonant frequency per unit volume of the stage. The proposed stage showed higher volume efficiency than other stages, which is due to the compactness of the proposed self-guided displacement-amplification mechanism.

	Proposed stage	Double-compound with bridge-type (Ref. 2)	Honeycomb stage (Ref. 3)	Unit
Travel range	963	119	400	μm
Resonant frequency	83	220	60	Hz
Max. operating voltage	150	120	150	V
Stage size	98 × 56 × 15	75 × 75 × 20	60 × 60 × 14	mm^3
Volume efficiency	0.97	0.23	0.51	$\mu m \cdot Hz/mm^3$

Table. 1 Performance comparison with other similar-sized nano-positioning stages

ACKNOWLEDGEMENT

This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Korean government (numbers 2010-0015316 and 2010-0023337).

REFERENCES

1. C.-L. Chu and S.-H. Fan, “A novel long-travel piezoelectric-driven linear nanopositioning stage”, Prec. Eng., Vol. 30, No. 1, pp. 85-95, 2006.
2. F. J. Shiou, C. J. Chen, C. J. Chiang, K. J. Liou, S. C. Liao, and H. C. Liou, “Development of a real-time closed-loop micro-/nano-positioning system embedded with a capacitive sensor”, Meas. Sci. Technol., Vol. 21, No. 5, 054007, 2010.
3. M. Muraoka, and S. Sanada, “Displacement amplifier for piezoelectric actuator based on honeycomb link mechanism”, Sensors and Actuators A: Physical, Vol. 157, No. 1, pp. 84-90, 2010.