A Millimeter-range Flexure-based Micropositioning Stage Using a Self-guided Amplifying Mechanism

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Abstract

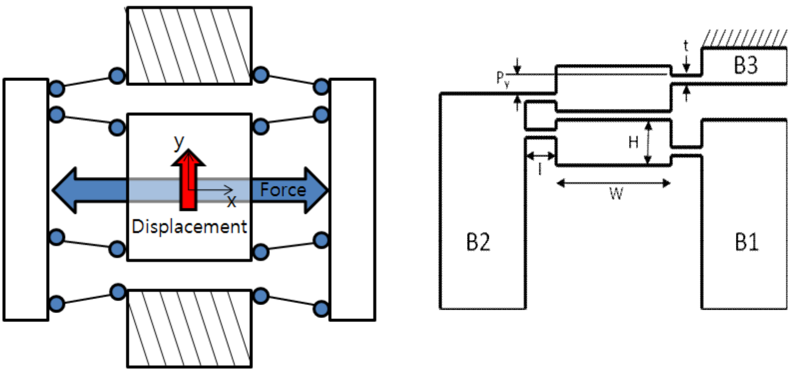
In this work, a new single-axis flexure-based micropositioning stage is proposed, which is guided by a skewed double compound parallelogram. This skewed double compound parallelogram gives a function of guide mechanism as well as a function of displacement amplifier. Using this self-guided amplifying mechanism, a long-range motion can be achieved within a compact size. For an example, we designed a millimeter-range flexure-based stage using a stack-type piezo-actuator. Leaf-springs are utilized for hinges, which can be monolithically machined by electric discharge machining.

1 Introduction

Micropositioning systems are essential to many fields such as scanning probe microscopes, micromanipulation and photolithography equipments. Flexure-based, piezoelectric stack-actuated micropositioning stages are widely used as micropositioning system because it has a high resolution, a compact size and a simple mechanical structure. In most cases, those stages utilize a displacement amplifying mechanisms due to the limited displacement of a piezoelectric stack [1-3]. High force generated by the piezoelectric stack enables high amplification ratio. Moreover, a compromise between bandwidth and travel range makes a wide variety of micropositioning stages: dynamics-oriented design [1] or range-oriented design [2]. However, the need of a displacement amplifying mechanism makes the stage complex and bulky. A bridge-type amplifying mechanism has many advantages over a lever-type one: a compact size, high efficiency and small parasitic stiffness. Since a bridge-type has a small transverse stiffness and a rotational stiffness, the improvement has been developed. [3] In this paper, we propose a single-axis flexure-based micropositioning stage that incorporates bridge-type displacement amplifying mechanisms to a double compound parallelogram guide.

2 Concept

Figure 1(a) shows a concept of the self-guided displace amplifying mechanism. The lateral displacement from the piezoelectric stack is amplified and transferred to the longitudinal motion of the moving body at the center. To implement this concept, we used leaf spring as pivots and rectangular bars as links. The actual geometric model is shown in Fig. 1(b). Based on the dimensions of the flexure hinges and the matrix method, a kinematic model and a dynamic model are derived.



(a) (b)

Figure 1: A self-guided double compound parallelogram (a) conceptual schematics (b) geometric model of hinges, links and bodies

3 Parametric analysis

By means of analytical models, the stage is optimized to get a highest resonance frequency under the constraints of size, maximum stress and a millimeter-range. Among five geometric parameters shown in Fig. 1(b), the link length (W), the link height (H) and the hinge length (l) have relatively less influence on a resonance frequency, maximum travel range and maximum stress which are the most important performance indexes. Thus, detail investigations on the offset between two hinges (P_y) and the hinge thickness (t) are presented here. As shown in Fig. 2, the resonance frequency is highly sensitive to the hinge thickness but less to the offset. However, both travel range and the maximum stress are very sensitive to both parameters. It means that smaller offset gives higher amplification but simultaneously induces higher stress. If we constrain these conditions, an optimized solution can be obtained.

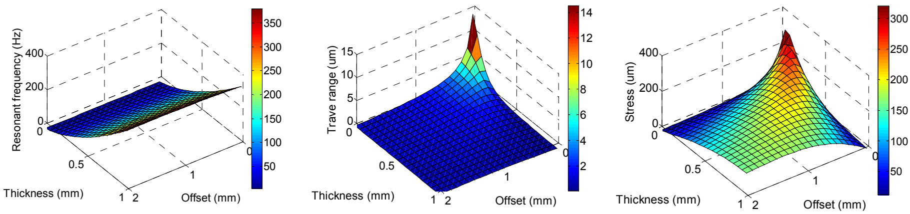


Figure 2: Parametric analysis varying the offset and the hinge thickness

Table1: Design results from the analytical model and finite element method

	Analytic model	FEM
Max. travel (μm)	1206	1179
Natural frequency (Hz)	89.4	77.4
Blocking force (N)	246	209
Max. stress (MPa)	139	121

4 Prototype design and experiments

Table 1 presents the specifications of a prototype which is optimized to achieve a millimeter-range. The prototype has an offset (P_y) of 1.2mm and a hinge thickness (t) of 0.4mm. Through finite element analysis, the analytic model was verified. Because the bodies are considered as rigid ones in the analytic model, the discrepancy has occurred. Actually the flexible bodies degrade the performances of the flexure-based micropositioning stage. Especially in our mechanism, transverse deflection of the body B2 can be critical. A piezoelectric stack (P-235-40, Piezojena) has a free displacement of 80μm at 150V and a stiffness of 50N/μm. The stage is monolithically machined by wire electric discharge machining from AL7075-T6. The size is 120mm×120mm×15mm. The fabricated prototype and the experimental setup are shown in Fig. 3. The laser interferometer (RLD10, Renishaw) was used to measure the displacement. Fig 4 demonstrates the maximum displacement is 960μm. The discrepancy between the modelling and the experiment might be caused by the tolerances in machining, especially with the thickness of springs or with the filleted corners. The resonant frequency was 83Hz which corresponds with the modelling. Also, we obtained a ±10nm resolution. This is same as the sensor's minimum resolution.

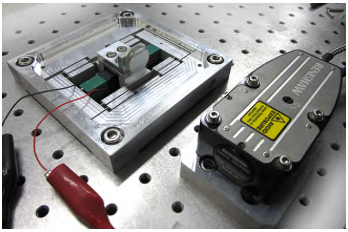


Figure 3: Experimental setup

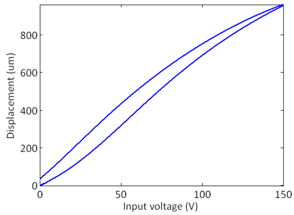


Figure 4: Maximum displacement

5 Conclusions

We proposed a simple and compact micropositioning stage. Using a skewed double compound parallelogram, both functions of motion guide and displacement amplifier are incorporated in one mechanism. A millimeter-range flexure-based stage using the proposed mechanism successfully demonstrates the effectiveness.

Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MEST) (No. 2009-0067920)

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