Design and Analysis of In-Plane Ultra-Precision XYθ_z Positioning Stage with Cymbal Guide and Scott-Russell Mechanism

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Abstract

This paper presents the design, finite element analysis, and experimental results of a new ultra-precision XYθ_z positioning stage with serial kinematics between parts for translational motion and rotational motion. The stage is actuated by three commercial stack type PZT actuators. Two translational motions are guided by four cymbal mechanisms. The cymbal mechanisms of proposed XYθ_z stage have functions of not only motion guide but also motion amplifier. And, the leaf spring guides a rotational motion which is amplified by the Scott-Russell mechanism. Finite element analysis was carried out in order to predict the XYθ_z stage performance, which will be validated by experimental results. The size of a prototype XYθ_z stage is 240 x 240 x 25 mm^3. The 1st resonance frequencies of the translational motion part and the rotational motion part were 145Hz and 125Hz. The translational motion travel range is 50 x 50 μm and the rotational motion range is 1 mrad.

1 Design and Analysis

In various fields of SPM (Scanning Probe Microscope), micro-fabrication, micro-aligner, and micro-assembly industries, three degree-of-freedom (XYθ_z) micro-positioning stages are applied [1-3]. To achieve the general requirements of each application such as high accuracy, fast response, and small parasitic motion, PZT actuators and flexural guide mechanisms are used. The proposed XYθ_z stage design is composed of two motion parts with serial kinematics. One is the translational motion part with four cymbal mechanisms. The other is the rotational motion part with the Scott-Russell linkage mechanism and leaf spring guide as shown in Fig. 1. The

central part of the stage is fixed to the ground, and the octangular outer part is a moving part.

Two translational motions (F_x, F_y) are generated by PZT actuators. By the force F_x, the length between s_1 and s_2 in the cymbal mechanism increases and the length between s_3 and s_4 decreases. Simultaneously, on the opposite side cymbal mechanism (2), the vertical length decreases and the horizontal length increases.

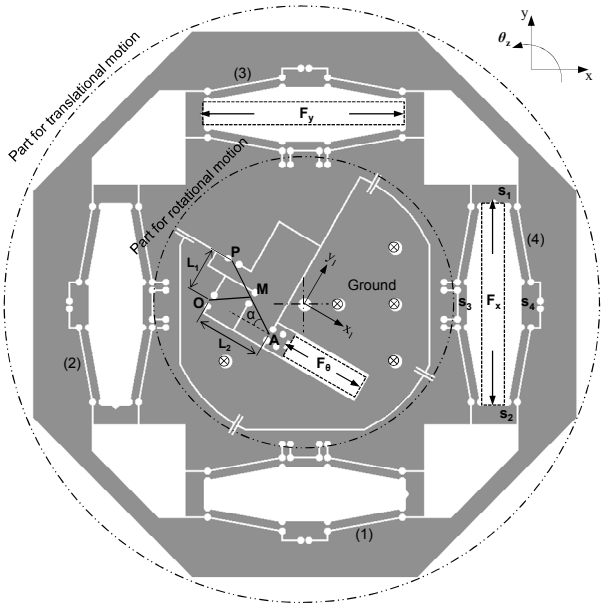

Fig. 1 XYθ_z Positioning Stage design

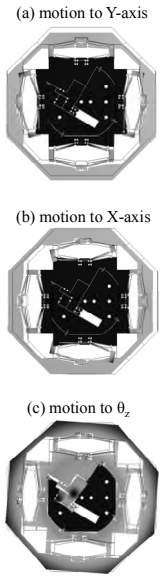

Fig. 2 Simulation results

Thus, the octangular outer part moves in the x-axis direction as shown in Fig. 2 (b). In this translation motion, both two cymbal mechanisms (1) and (3) have a function of motion guide. By the elastic deformation of flexure notch hinges which are linked with the ground part and moving part, guide cymbal mechanism (1) rotates clockwise and (3) rotates counter-clockwise. Therefore, cymbal mechanism (3) and (4) are not only motion amplifier but also motion guide. In the case of translation motion to Y-axis direction, the cymbal mechanism (3) is motion amplifier and the cymbal mechanism (2) and (4) are motion guide. The proposed stage has a symmetrical structure formed by four in-plane cymbal mechanisms. In this proposed XYθ_z stage, Scott-Russell linkage mechanism (SRLM) is used for a rotational motion amplifier.

As shown in the rotation part of Fig. 1, links of SRLM is designed with flexure notch hinges. SRLM is consisted of link AP and link OM. By the force F_θ of PZT actuator, end point A of link AP move towards point O along x_1-axis and end point P recedes from point O along y_1-axis. Then, the link AP rotates by the link OM which is fixed on point O. The magnification ratio of rotational motion is determined by the ratio of L_1/L_2. Rotational motion guide of the proposed stage is four leaf springs as shown in Fig. 2 (c). While in rotational motion, translational mechanism part is not affected by rotational mechanism part, because the proposed stage design is based on serial kinematics. Fig. 2 shows finite element analysis simulation results with a commercial program ANSYS^{TM}. Black lines present the initial undeformed part of the stage.

3 Experimental Set-up and Results

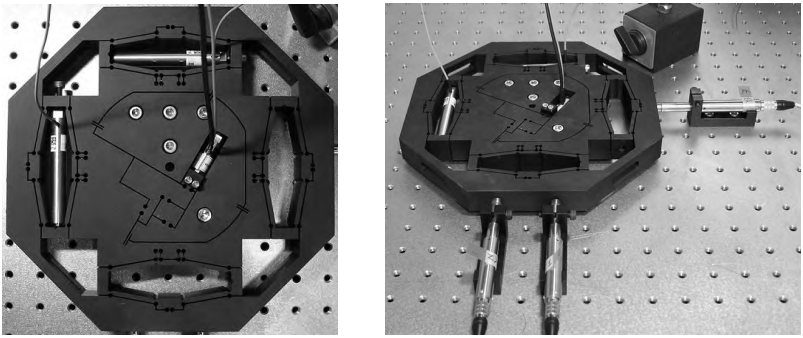

Fig. 3 (a) fabricated XYθ_z stage (b) Capacitance sensor probes set-up

A designed XYθ_z stage was precisely fabricated using wire-EDM with AL6061-T6. The fabricated monolithic prototype stage was assembled with 3 piezo actuators by bolting as shown in the Fig. 3 (a).

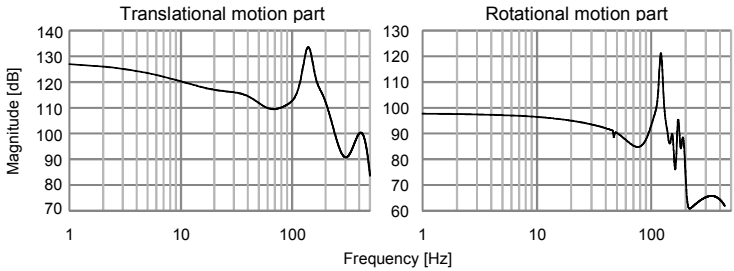

Fig. 4 Frequency response experimental results of XYθ_z Positioning Stage

As the results of frequency response experiments, the 1st resonance frequencies of each translational motion part are 145 Hz as shown in the Fig. 4. The reason is that part for translational motion is designed with symmetrical configuration of cymbal mechanism. And, the 1st resonance frequency of part for rotational motion is 120 Hz.

4 Conclusion

This paper describes the design, analysis, fabrication, and experimental results of an ultra-precision XYθ_z positioning stage. With cymbal mechanism and Scott-Russell linkage mechanism, XYθ_z stage has been designed with serial kinematics between parts for translational motion and rotational motion. By the simulation result of finite element analysis, performances of proposed stage were validated. Notably, the small parasitic motion errors and 1st resonance frequency which is higher than 100Hz were verified. As the experimental results of frequency response test, a translational motion part has the symmetrical configuration.

Acknowledgement

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