Ultraprecision XY stage with millimetre travel range using leaf-spring mechanism and voice-coil motor

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Introduction

Nowadays, manufacturing technologies such as machine tool and semiconductor manufacturing processes and measuring technologies such as scanning probe microscopes are rapidly processed and stimulate the development of precision positioning devices. Fukada[1] divided current precision positioning mechanisms into two categories, based on different fields of applications. One is the positioning mechanism with a long stroke mechanism, and the other is the fine positioning mechanism. But, precision positioning mechanism with nanometer resolution and millimeter travel range is rarely developed.

This article presents the design and performance evaluation of a compact ultraprecision XY-stage with nanometer accuracy and large travel range. The specifications of XY stage are 2mm travel range and the limited total size of 100mm×100mm×50mm and resolution less than 10nm.

Conceptual design

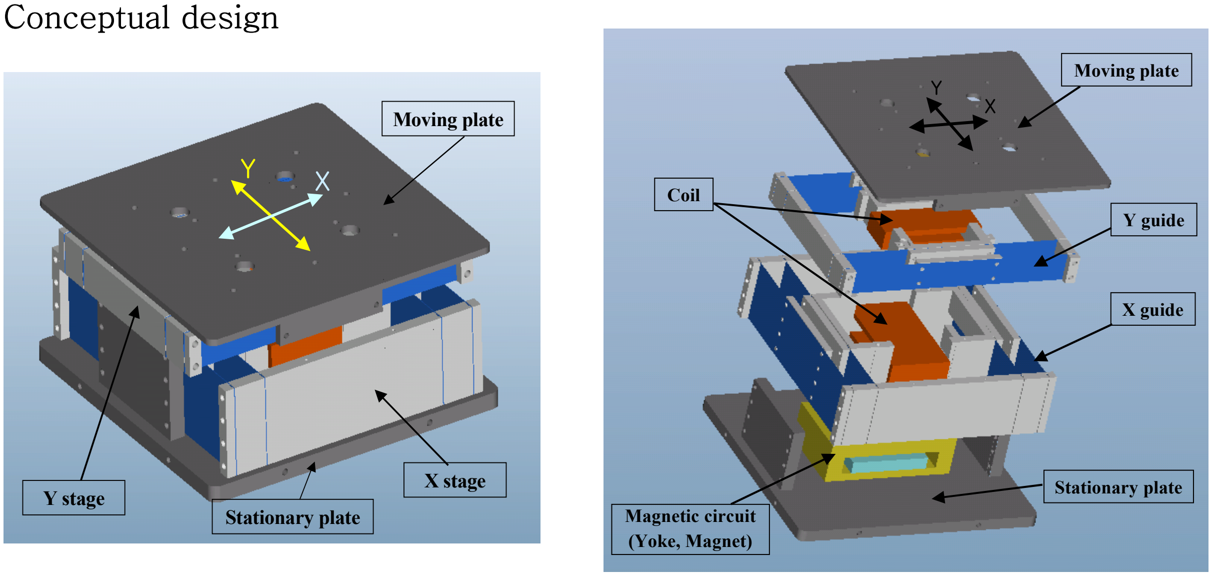


Fig. 1 Structure of proposed XY-stage

The proposed XY-stage is stacked type that Y-stage is piled up on X-stage orthogonally. Two stages are combined with each other by center part wound with coil. Each stage has the same structure with flexure (leaf-spring) guide whose type is double compound linear spring[2] and VCM (voice-coil motor) actuator. The flexure guide mechanism provides good accuracy due to the characteristics of negligible backlash and stick-slip friction, and smooth, continuous motion. Though monolithic structure is more proper, assembly structure must be used in this system since we can't manufacture a small thickness monolithic leaf-spring guide, which is necessary for large travel range. VCM also has inherently infinite resolution. But the moving part of VCM is different in each stage. X-stage is 'moving coil' type and Y-stage is 'moving magnet' type. Fig. 2 shows the structure of one-axis stage (X-stage).

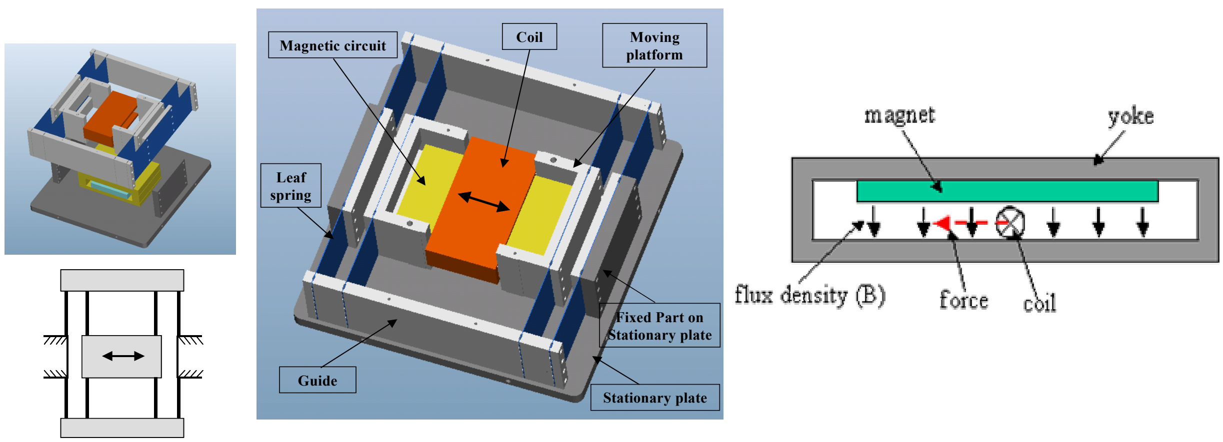


Fig. 2 Structure of X-stage

Modeling & Opimal design

Because the relationship between design variables and system parameters are quite complicated, it is very difficult to set design variables manually. Therefore optimal design is used. The cost function of optimal design is to maximize the 1st natural frequencies of XY-stage. It guarantees fast response.

As optimal design requires static and dynamic characteristics of stage, modeling of stage must be accomplished. Permeance method that gives magnetic flux density at air-gap is used to predict the actuating force of VCM and generalized computer-based method that automatically generates equations of motion and solves them numerically is used to predict static and dynamic characteristics for flexure mechanism. Latter is proposed by Ryu.[3] A little modification of flexure stiffness matrix and pivot point is required to apply his method to leaf-spring mechanism.

For the solution, a sequential quadratic programming (SQP) method and MATLAB have been used. The designed resonant frequencies are 29.169Hz for x-axis and 26.523Hz for y-axis. Fig. 3 shows a designed frequency response function (FRF) of each axis.

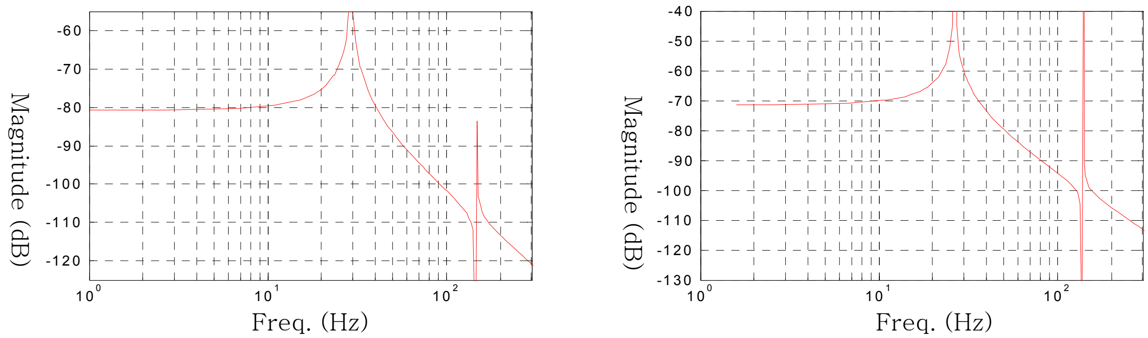


Fig. 3 Frequency response function of x, y axis

Performance evaluation

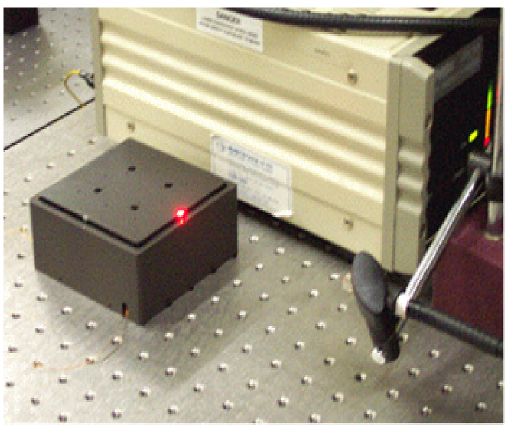


Fig. 4 Experimental setup

Fig. 4 shows the experimental setup. LDV (Laser Doppler Vibro-meter)(Polytec. OFV 501, OFV 3001) with minimum resolution of 2nm is used to measure the position. Two experiments is carried out to evaluate the performance of stage. The first is to measure the frequency response characteristics using sine swept mode of Dynamic signal analyzer (Hewlett Packard 35670A) and the results follow as fig. 5. The resonant frequencies are 26.68Hz for x-axis and 22.79Hz for y-axis.

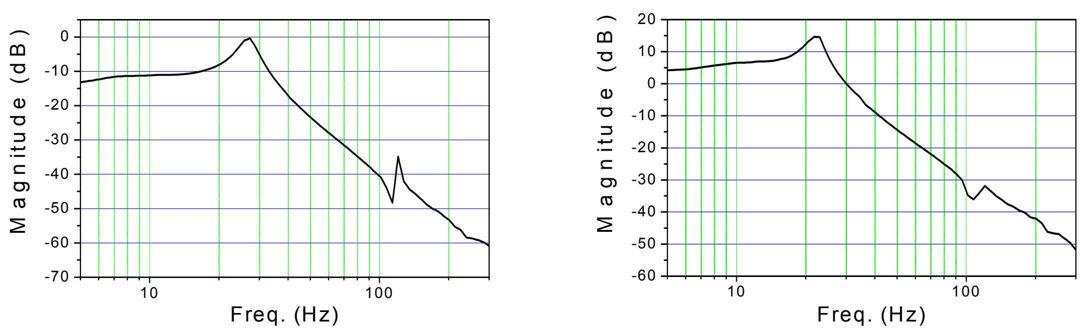
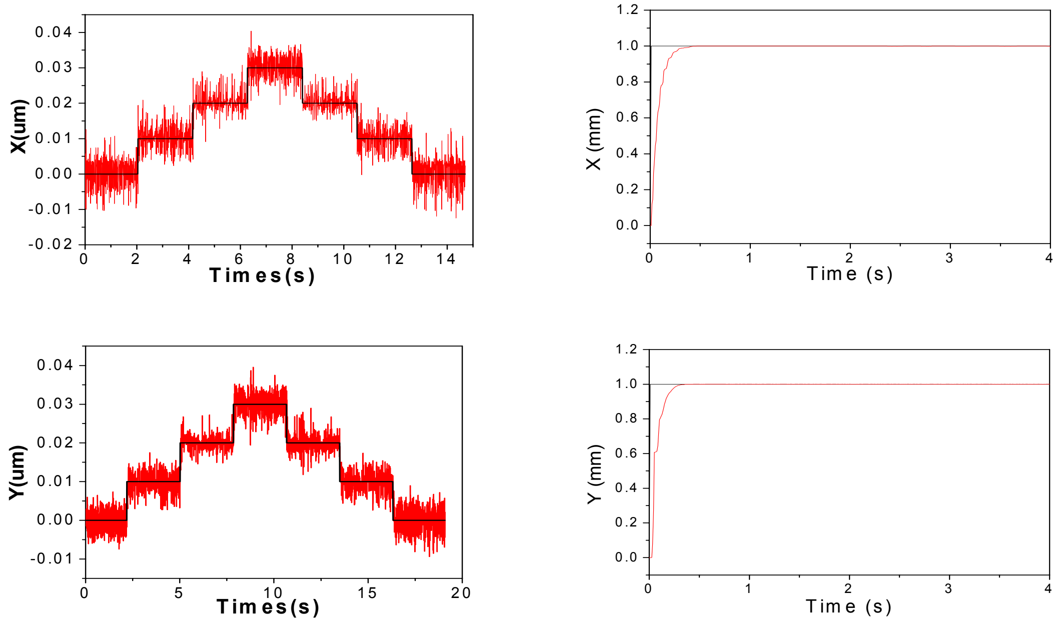


Fig. 5 Experimental results of XY stage (FRF)

The second is to evaluate the positioning performance using PID controller. The control is performed by PC using 12 bits D/A and A/D converter (AT-MIO-16E-1, National Instrument Corp.) Fine position with resolution 10nm is realized and 2mm travel range is also realized.



(a) Fine motion (b) Over 2mm stroke (forward direction)

Fig. 6 Experimental positioning performance

Conclusions

1. Ultra-precision compact XY positioning mechanism with 10nm resolution over 2mm travel range is realized using leaf spring guide and VCM actuator. Its first resonant frequencies are 26.68Hz for x-axis and 22.79Hz for y-axis.
2. Modeling is verified via experiment and we assure the deviation less than 10%.

References

[1] S. Fukada, T. Shibuya, "Ultra-precise Positioning with Nanometirc Resolution over A One-Millimeter Stroke Using Flexure Guide And Electro-magnetic Linear Motor," Proc. of the 3rd [8] euspen International Conference, 2002, 171-174

[2] Smith S. T., Chetwynd D. G. "Foundations of Ultrapercision Mechanism Design," Gordon&Breach, 1992

[3] Jae W. Ryu, D.G. Gweon, Kee S. Moon, "Error analysis of a flexure hinge mechanism induced by machining imperfection," ASPE, Vol. 21, No. 2/3, pp. 83-89, 1997