

# Multi-Axis Nano Positioning Flexure Stage Using Magnetically Preloaded PZT Actuator

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## Abstract

This paper presents a novel 3-axis fine positioning stage using magnetically preloaded PZT actuators. All the procedure concerning the design, fabrication, experiment and performance evaluation of the stage are described. The stage considered here is composed of flexure hinges, piezoelectric actuators and their peripherals. A special flexure hinge is adopted to actuate the single stage in three axes at the same time. The developed stage makes use of magnetically preloaded PZT actuators and a ball contact mechanism to avoid the cross-talk among the axes. The structural design for the stage is analyzed and optimized with the help of a finite element computer simulation. Performance evaluation is also made for the PZT actuators as well as the stage positioning accuracy. Experimental results show that the developed stage is accurate enough to be used for nanometer positioning.

## 1. Introduction

With the increasing demand on more precise and higher speed stages, nano positioning stages have attracted much attention. Recently, several types of PZT driven nano positioning stages have been developed to assess more rapid response and higher precision. In particular, many researchers and industry are concerned with multi-axis nano positioning stages because of their usefulness in semi-conductor manufacturing systems and scanning apparatus [1,2].

This paper introduces a novel multi-axis stage using magnetically preloaded PZT actuators. The developed stage has various advantages in implementation for multi-axis positioning systems: the magnetically preloaded PZT actuators allow longer stroke; the motion crosstalk is minimized by using a ball contact mechanism between the moving part and the fixed part; the proposed stage is realized to be more compact than other stages by realizing 3 axis motion mechanism based upon a single moving stage.

The structural design for the stage is analyzed and optimized with the help of a finite element computer simulation. Experiments are also performed to investigate the performance of the developed, 3-axis nano positioning stage using magnetically preloaded PZT actuators. Throughout the experiments, it is validated that the proposed stage has good performance in accuracy.

## 2. Design, Modeling and Analysis of Stage

Figures 1 and 2 show the actual stage and the zoomed view of flexure hinge used. Figure 3 is a PZT actuator assembly to drive stage, in which an upper flux plate is installed at the stage moving part and a permanent magnet is employed to provide magnetical preload. The PZT stack, which has the length of 40 mm, is capable of producing maximum stroke of 30  $\mu$  m with the open-loop resolution of 0.3 nm. The push and pull force capacity are 1000N and 5N, respectively. Since the PZT stack is fragile under tensile loading condition, it is important to preload the stack in order to prevent any damage from dynamic tensile loads. It is recommended [1] that the preloading force be around 20 percent of the maximum force capacity to preserve sufficient stroke, while protecting the stack from damage. For magnetic preloading, permanent magnets made of Nd-Fe-B are adopted. The outer and inner radii of the permanent magnets are 15mm and 6 mm, respectively, and the axial length of the magnets is 25mm. Figure 4 shows a ball( $\phi = 2\text{mm}$ ) joint between the plate and PZT actuator. The purpose of the ball joint is to eliminate motion crosstalks. Flexure hinge is adopted to actuate the single stage in three axes at the same time. A numerical analysis based on FEM is made to obtain best parameters for flexure hinge.

## 3. Fabrication and Preliminary Experiment

The characteristics of the developed stage is summarized in Table 1. The stage is made of aluminum and the magnetical preloading system makes use of a permanent magnet. A preliminary experiment is made to verify the design procedure based on FEM modeling and formula. Figure 5 shows the measured frequency response function, in which the measured and computed natural frequencies are indicated. The figure confirms that the proposed analysis method is accurate enough to be used in the design procedure. On the other hand, the magnetic preload can affect the dynamic characteristics of the stage. Figure 6 shows the change of natural frequencies with the variation of the preload given to each moving axis. It can be concluded that the preload increases the natural frequency. This is believed to be due to the ball contact mechanism, of which stiffness is significantly affected by the preload [3].

## 4. Performance Evaluation

To evaluate the developed stage, maximum strokes and resolutions about input voltage(0~120V) are measured. An experiment to investigate the decrease of maximum stroke with magnetically preload is also made. The open-loop characteristics of the magnet-preloaded actuator are measured and compared to those of the spring-preloaded actuator. Figure 7 shows the input-displacement curves with the magnetically preload changed. It is clearly shown that the magnetically preload does not significantly affect the stroke. Figure 8 illustrates the step responses for the stage. Figure 9 shows step tests with 10nm resolution for X and Y axis and with 0.012  $\mu$  rad resolution for  $\Theta$  z axis. The results of stroke and resolution of stage verifies the developed stage is useful as a nanometer positioning system.

## 5. Concluding Remarks.

In this paper, a novel 3-axis fine positioning stage with nanometer resolution is presented. The developed stage features a single module based multi-axis positioning system. The stage employs the magnetical preload. The design procedure is also presented and verified through an experiment. The accuracy of the developed stage is evaluated with step tests. The experimental results show that the presented stage may be useful for precision equipment.

## Acknowledgment

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### References

- [1] Physik Instruments, Tutorial: Piezoelectrics in Positioning, <http://www.physikinstrumente.com>
- [2] S.T. Smith: Flexure(Gordon and Breach Science Publishers, 2000).
- [3] Harris, T.A., Rolling Bearing Analysis, John Wiley & Sons, Inc., 2001.

Table 1 Specifications for stage

Category	Item		Data
Stage	Material	Type	Al 7075-T6
		Density	2810 kg/m <sup>3</sup>
		Young's modulus	72 GPa
	Mass of moving part	Without accessories	0.796 kg
		With accessories	0.977 kg
PZT actuator	Type		PSt 150/7 × 7/20
	Max. Stroke		30 μm
	Stiffness		120e6 N/m
	Preload		Permanent magnet

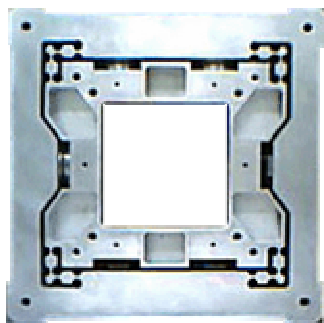


Fig. 1 The developed fine stage



Fig. 2 The flexure hinge

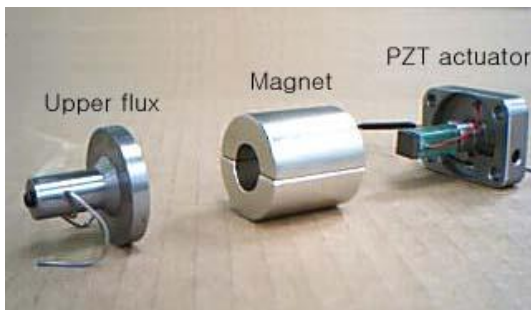


Fig. 3 The PZT actuator assembly



Fig. 4 Ball joint with φ 2 mm ball

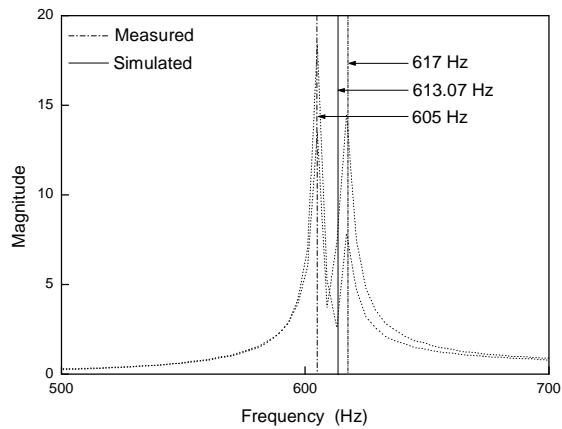


Fig. 5 Frequency response and the natural frequencies of stage moving part without accessories

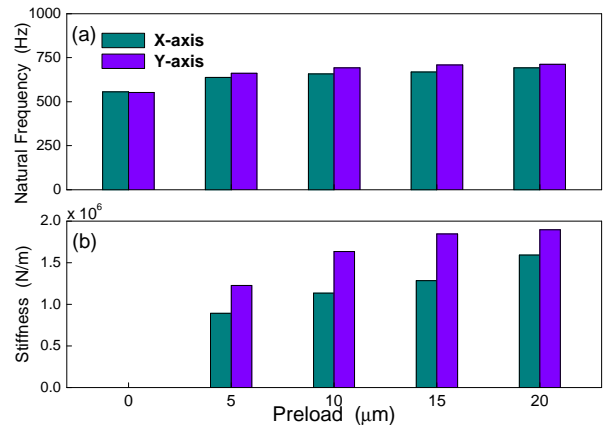


Fig. 6 Changes of the 1<sup>st</sup> natural frequency and added stiffness with the preload varied

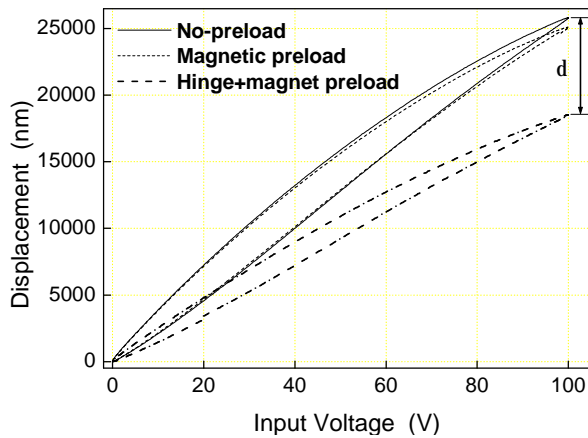


Fig. 7 Comparison of hysteresis loops with and without preloads

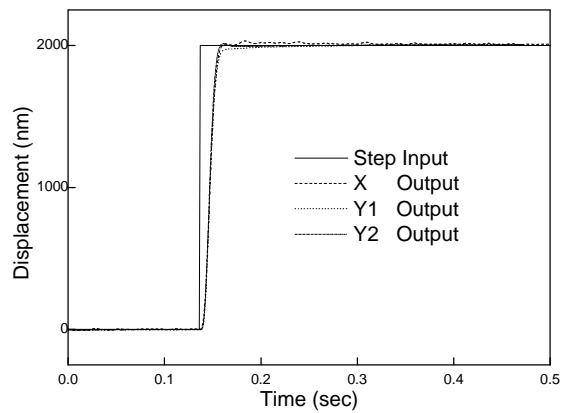


Fig. 8 Step responses

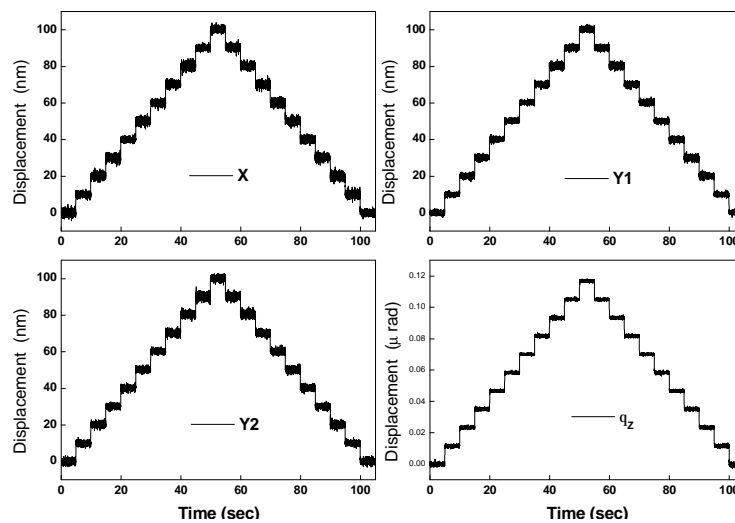


Fig. 9 Step tests with 10 nm and 0.012  $\mu$  rad resolutions