A High Speed Portable XY Flexure-based Nano Positioning Stage

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Abstract— Nano positioning systems are widely used in nanotechnology equipments such as Scanning Probe Microscopes (SPM), Nanofabrication systems etc., This paper is mainly focused on the development of portable XYZ nano positioning stage which can provide nano-metric motions at high speed with nanometer resolutions. The work includes design considerations for flexure based nano positioning systems, fabrication of monolithic flexure based stage, integration of piezo-actuators and capacitive sensors. The developed nano positioning system has been tested for resolution, linearity's, hysteresis, creep and thermal drift in open-loop and closed loop.

Key words: Piezo-based Systems, Flexure, Nanopositioning System, Closed Loop System

I. Introduction

Nanotechnology has been diversified its applications from computer disks, semiconductor devices, medicine, biotechnology so on. In order to meet the positioning requirements of nanotechnology such as micro manufacturing to scanning probe microscopes, nanopositioning capabilities with nano-metric accuracies with high speed motions are required. High performance positioning systems are important to meet the rapid growing of MEMS/NEMS, semiconductor and precision manufacturing process. The compliant structures associated with the piezo actuated systems for producing the fine motion with integrated closed loop nanopositioning systems are used to provide fine motions.

The nanopositioning systems are micro-scale[4] mechatronic systems which are capable of nanometric precision, accuracy, and resolution, and are useful for scanning probe based microscopy, manipulation, and manufacturing. Flexure mechanisms are the most common bearing choice for nanopositioning systems due to the advantage that they provide like low friction and backlash in their motion.

The flexure-based stages are used as nano-positioning systems because they have several advantages including high resolutions, compact size, quick dynamics, and simple mechanical structure. The major drawback of flexure-based piezo-stage is small range of motion. In order to overcome this drawback, most conventional flexure based nano-positioning stages use serial combinations of motion guide with amplification mechanism. The serial combination makes the size of the stage large and limits the small scale requirements.

The most challenge is not only in the creation of a multi-axis flexure mechanism with higher range of motion with minimum unwanted motion in other axes.

Yangmin Li and et.al [1] have designed XY parallel stage with decoupled motion. The design is based on the double parallelogram flexures with a compact displacement amplifier and better stiffness. Kinematic design & modelling of the stage has been carried based on stiffness matrix and compliance which are validated using finite element analysis. The cross axis motion is less than 1.8% with natural frequency of 110Hz for a stroke of 117µm of the designed stage.

Shorya Awtar and et.al [2] has been designed a parallel kinematic XY flexure mechanism for large range of motion based on constraint patterns without. The flexure based mechanism is performed through non-linear analysis. The system is designed with high degree of symmetry, allows improved actuator isolation, less rotational errors & exhibits higher degree of stiffness against to fabrication and assembly errors. The positioning stage is designed for 5mm x 5mm, with less than 1% position error, cross-axis coupling and actuator isolation, and stage rotation is less than 1 arc sec.

Jingyan Dong and et.al [3] have developed XY nanopositioning stage based on a parallelogram hybrid flexure and a doubly clamped beam with compliant beams and circular hinges. The design mechanism decouples the motion in the X-Y direction and arrests parasitic rotations in the XY plane, which allows improved bandwidth. The positioning stage has resolutions down to 1nm, natural frequency more than 8 KHz for a range of 15µm.

Many researchers have tried to develop a nanopositioning stage having with higher resonant frequency, minimum parasitic motion errors and higher motion range.

II. Design Considerations & Finite Element Modeling of Nanopositioning System

Based on outcome of the literature survey, parallelogram flexure based mechanism is used for the development of nanopositioning stage.

Parameters	Specifications
Ranges of motion (XY)	60µm
Resolution (XY)	1.5nm
Repeatability	2nm
Resonant Frequency	460 Hz
Stiffness	1.4 N/µm
Maximum load	100 grams

Table 1: Specifications of the proposed Nanopositioning stage

The design of the XY stage is shown in Figure1 below, the orientation of the four chains is arranged in a way such that the prismatic joints are perpendicular to each other.

Fig. 1: Solid Model of XY Nanopositioning stage

Finite element analysis for the model for various materials is done using Ansys software, solid-20node186 element is which is a three dimensional second order element is used for analysis. Load of 1020N (Maximum load obtained from theoretical calculation) applied to check for maximum displacement of stage, which is 657.3 µm, with stiffness of 1.68 N/µm, with first resonant frequency of 1000.5 Hz.

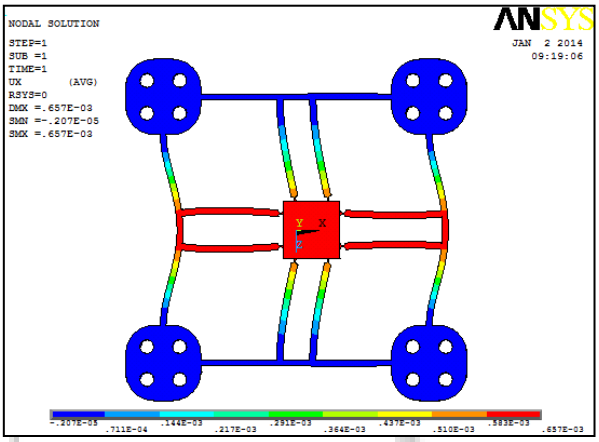

Fig. 2: Max Displacement at load 1020N

III. Fabrication of Nanopositioning Stage

The stage is fabricated using titanium alloy material using milling and drilling machining process to required shape. The mechanism is based on monolithic structure which is machined using EDM wire machine. Titanium is difficult to machine being poor conductor of heat.

IV. Testing of Nanopositioning Stage

The linear piezo-actuators are used for driving the mechanism due to dynamic application of the positioning stage. The preferred actuators are preloaded stack piezo actuators to drive the flexure stage due to its high bandwidth and stiffness is about 80N/µm as shown in fig(3).

Fig. 3: Piezo-stack actuators

The range of positioning stage is designed for 60 µm, hence to meet the requirement of the linear actuator a stack actuator is used, which requires input voltage of 1000VDC. Hence, high voltage amplifier is required to drive the stack piezoactuator. The voltage gain of the piezo high voltage amplifier is 100.

The major limitations of piezo-actuator are hysteresis, creep and non-linear behavior. The piezo actuator limits the system performance in-terms of positioning error, orthogonal error and accuracies of the positioning system. The open-loop piezo-actuated nanopositioning provides higher bandwidth with limitations in accuracies.

Fig. 4: Proportional Integral (PI) controller

To improve the positioning accuracies and enhance the nanopositioning system performance a closed loop operation is introduced as shown in fig4 by connecting capacitive sensors with linearity less than 0.5 nm to the stage as shown in fig5.

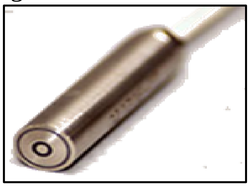

Fig. 5: Proportional Integral (PI) controller

V. Experimental Results & Discussions

A. Piezo-Actuator & Capacitive Sensor Results

The piezo-actuator & capacitive sensor has been tested its range, non-linearity and hysteresis studies separately to understand the in-accuracies due to flexure based nano positioning stage. The range of the piezo-actuator is shown in figure6.

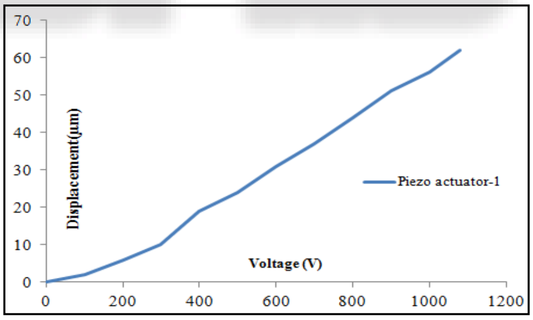

Fig. 6: Range of a piezo-actuator

The maximum non-linearity of the piezo-actuator is about 8.12 µm, which is around 13.096% of total motion.

The range of the capacitive sensor has been tested and shown in figure7. Two plate capacitive sensors were tested using high precision motion slides.

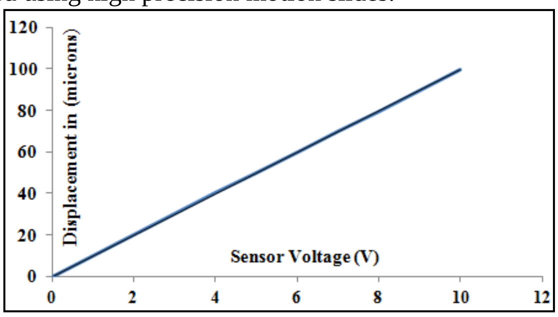

Fig. 7: Range of a capacitive sensor

Maximum Non-Linearity of 0.2309µm i.e.0.2296% of total motion.

B. FRF Measurement Test Results

The FRF measured is carried out on a positioning stage using impact hammer and frequency analyzer to study the dynamic characteristics of the positioning stage.

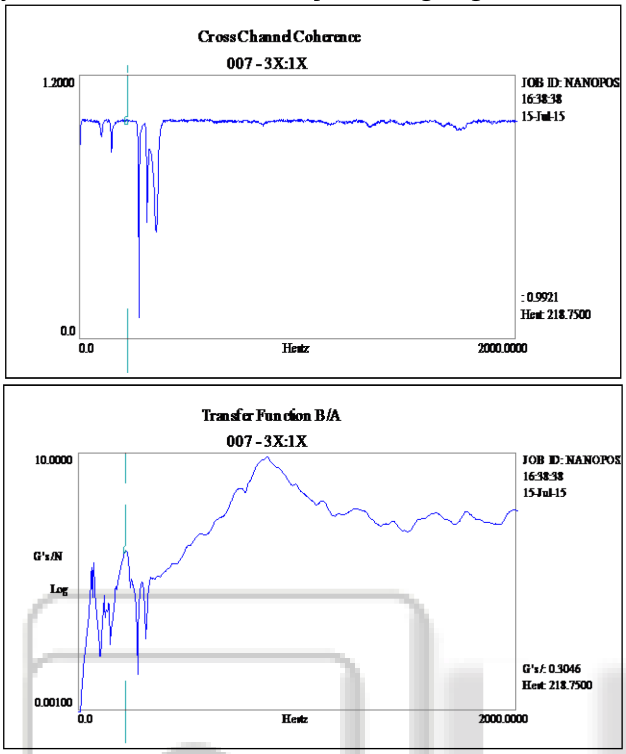

Fig. 8: FRF measurement on X axis

The cross channel coherence and transfer function of the stage in x –axis is shown in fig8.

Frequency (Hz)	Coherence
X Axis	
140.00	0.99
296.25	0.98
Y axis	
71.25	0.99
120.00	0.99
218.75	0.99
860.00	0.98

Table 2: FRF measurement results

The FRF measurement results shown in table2 clearly mentions that it can be used for high speed applications.

C. Open Loop & Closed Loop Testing

1) Static Testing

The open loop testing of the nanopositioning stage has been carried out and results have been plotted in figure9. The plot clearly shows that there is a hysteresis of about 12%, linearity 0.5% and repeatability of 1.2µm for full range.

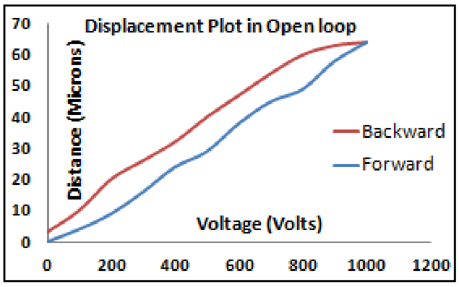

Fig. 9: Open loop results

The closed loop testing of the nanopositioning stage has been carried out and results have been plotted in figure10. The plot clearly shows that hysteresis of 1.72%, linearity of 0.03 and repeatability of 0.005 is achieved.

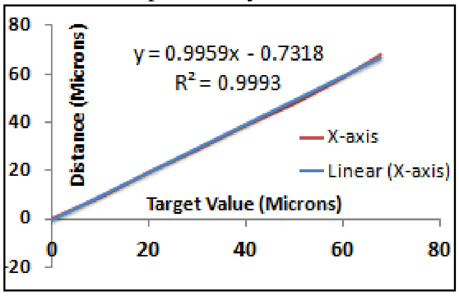

Fig. 10: Closed loop results

2) Dynamic Testing

The dynamic testing has been carried out on the Nanopositioning Stage (NPS), the triangular and sinusoidal waveforms have been applied to study the frequency range of the system. From the nanopositioning dynamic results of fig11 & fig12, the positioning error is negligible upto 15Hz for amplitude of 10µm.

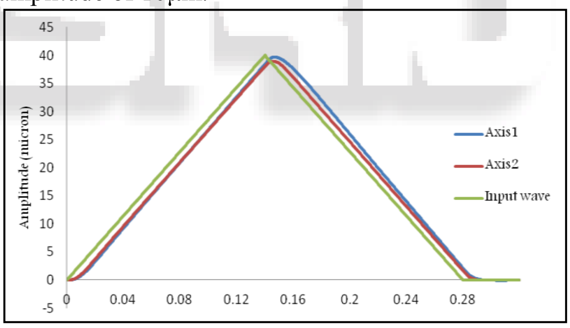

Fig. 11: Triangular input to NPS

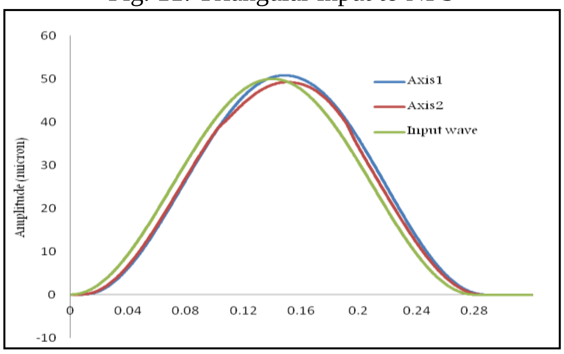

Fig. 12: Sinusoidal input to NPS

The developed nanopositioning system shown in fig13 has been tested for high speed applications.

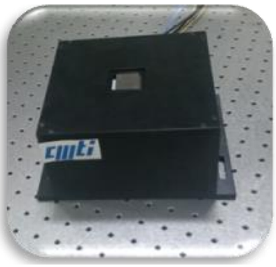

Fig. 13: Portable XY nanopositioning stage

VI. Conclusions

The static and dynamic testing of open loop and closed loop XY nanopositioning stage has been discussed. The closed loop result corrects the non-linear characteristics of piezo-actuator and flexure stage. The hystereses, non-linearity of closed loop system are minimized to 1% from 12% compared to open loop system. The XY flexure based nano-positioning stage is designed and tested successfully for high speed application upto 15Hz for amplitude of 10μm.

Reference

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