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Manufacture and experiment of a compliant parallel XY nano-positioning stage for high dynamic performance

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Abstract

Nano- positioning stage has been researched for many years and developed in various forms. This paper reports manufacture and experiment of a novel compliant parallel XY nano-position stage. The nano-positioning stage has two bridge amplification mechanisms to improve working range of the stage, double four bar mechanisms and two parallelograms to guide X and Y directional motions suppressing parasitic motions. The nano-positioning stage was manufactured with optimized geometrical dimensions. Voltage amplifiers which apply voltage to actuators, sensor drivers and digital signal processing controller were set up for experiments. Resolutions, working range and runout of yaw motion were measured by the installed system. Resolutions of 3nm for both X and Y axes, working range of 120µm for both axes and runout of yaw motion of 9 µrad (X axis) and 14.5µrad(Y axis) were measured.

Keywords: nano-positioning, Flexure, Piezoelectric actuator, parallel structure

1. Introduction

Nano-positioning stage has been researched for many years by many researchers. Y. Li et al developed a decoupled micro-motion stage which first resonant frequency is 750.52Hz. However, it has small working range of 19.2µm × 8.8µm because of high stiffness of the structure of the stage [1]. Parasitic motion of the stage is about 1µm. Compared to the range of the stage, the parasitic motion is quite large. Y. Qin et al developed a stage which has small working of 11.6µm × 11.6µm. The stage has first resonant frequency of 665.4Hz [2].

In this paper, manufacture and experiment of a compliant parallel decoupled XY nano-position stage are presented. Working range, runout, parasitic motion and natural frequency of the stage were considered in an optimization process [3]. Resolution, working range, and runout which are basic performances of the nano-positioning stage were measured.

2. Manufacture of nano-positioning stage

For concept design, the stage has been chosen to have two bridge amplification mechanisms to improve working range. Furthermore, double four bars and two parallelogram flexures are employed to guide X and Y directional motions in order for suppressing parasitic motions. In order to manufacture the nano-position stage, optimal design for maximizing first resonant frequency was performed [3]. By the optimization of the stage, optimized geometrical dimensions of the stage were derived. Target performances of the stage are: working range longer than 120um for each axis and runout of yaw motion smaller than 10urad when the stage moves along the X and Y axes.

In order to measure displacement of the nano-positioning stage, capacitive sensors were used. In figure 1, the structures holding the capacitive probes are shown.

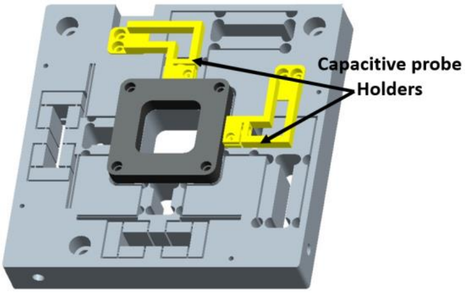

Figure 1. Location of capacitive probe holders

The nano-positioning stage was manufactured with the optimized geometrical dimensions. Material for the nano-positioning stage is chosen as AL7075-T6 because of its high stiffness and easy machinability. In order to eliminate assembly error, the stage was manufactured with monolithic machining method which does not need any parts to be assembled. In order for machining slim slots, wire-cut electrical discharge machining was used. The manufactured stage is shown in figure 2. The exterior size of the stage is 150mm × 150mm × 30mm.

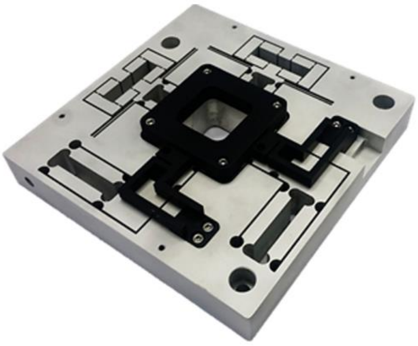

Figure 2. Manufactured compliant parallel XY nano-positioning stage

3. Experiments

In order for operating the nano-positioning stage, capacitive sensor drivers, voltage amplifiers which supply voltage to piezoelectric transducer (PZT) actuators, and digital signal processing controller were set up as shown in figure 3.

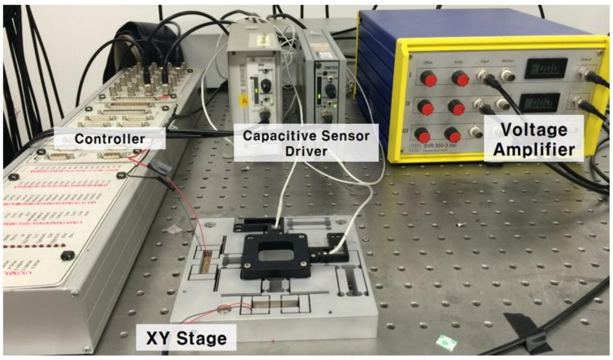

Figure 3. System set up for experiments of the nano-positioning stage

The nano-positioning stage is decoupled system, which means that single actuator only generates single directional force, not generating other directional forces. The decoupled system can be achieved by guiding mechanisms [3]. Therefore, any decoupling process such as mathematical computation is not necessary.

Signal flowing procedure of the system is as in the following. After the capacitive sensors (CPL190, Lion Precision) measure displacement, it is transmitted to the digital signal processing controller (dS1103, dSPACE). Then, the digital signal processing controller calculates how much of force should be generated by comparing reference input and the displacement. The digital signal processing controller sends signals of how much of voltage should be applied to the voltage amplifier (SVR 350, Piezomechanik, GmbH). Finally, the amplifier applies appropriate voltage to the PZTs (P-887.91, PI), making closed-loop control sequence.

After setting up the system, experiments for resolution, working range were carried out. Result of the resolution is shown in figure 4.

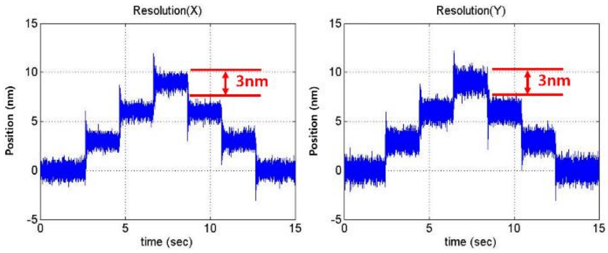

Figure 4. Experiment result of resolution of X and Y axes

Result of the working range is shown in figure 5.

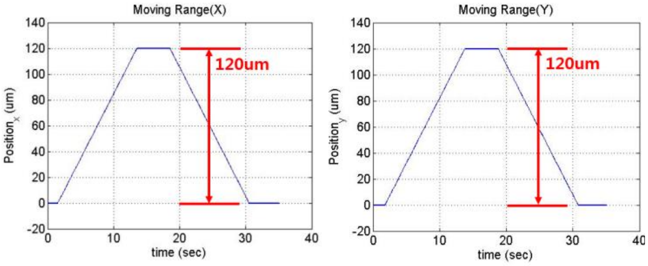

Figure 5. Experiment result of working range of X and Y axes

Resolution of the stage was measured 3nm for both axes and working range of the stage was measured 120μm for both axes.

In order to measure runout of yaw motion and parasitic motion, laser interferometers (RLU10, Renishaw) were used. For the calculation of the yaw motion, two laser interferometers measured displacement and the displacement from two laser interferometers divided by distance between the two laser interferometers in order for calculating yaw motion.

Since laser beam emitted from the laser interferometer should be reflected from the moving part of the stage, a mirror is attached on the moving part of the stage perpendicular to the laser beam as shown in figure 6.

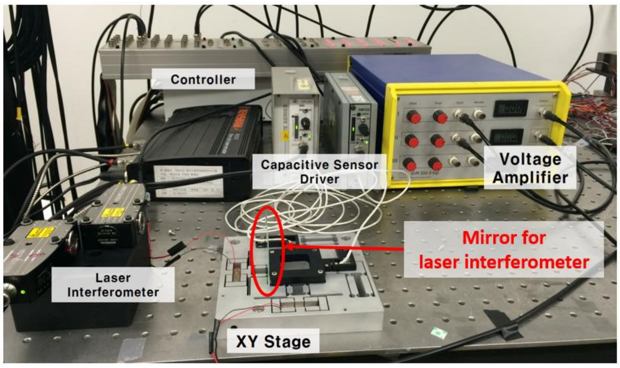

Figure 6. System set up for runout experiment

Runout of yaw motion was measured while the stage moves along the X or Y axes with maximum working range. The capacitive sensors were used for the closed-loop control and the laser interferometers were used for measuring yaw motion of the stage. Result of runout was measured 9μrad for X axis and 14.5μrad for Y axis.

Parasitic motion was measured while the stage moves along the X or Y axes with maximum working range. Result of parasitic motion was measured 0.78μm for X axis and 0.45μm for Y axis.

4. Conclusions

In this paper, manufacture and experiment of a compliant parallel decoupled XY nano-position stage were carried out. Resolution, working range, and runout which are the basic performances of the nano-positioning stage are measured 3nm for both axes, 120μm for both axes, and 9μrad for X axis and 14.5μrad for Y axis, respectively.

In order to achieve decoupled motion, combination of double four bar and parallelogram guide mechanisms are used. The parasitic motion of the stage was measure 0.78μm for X axis and 0.45μm for Y axis. Compared to other stages developed, the proposed stage has small parasitic motion due to optimization and combination of double four bar and parallelogram guide mechanisms.

Thanks to its compactness and good performances including high resolutions and long working range, the proposed stage is expected to be adopted in many applicable fields.

Applications of advanced control strategies and getting high dynamic performances will be future work for the stage.

References

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