The New Long Range Multi-axis Nanopositioner
using Inertial Slider/Walking Method

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Introduction

Ultraprecision positioning mechanism with both long moving range and nanometer resolution is more and more required in the field of precision engineering and many efforts are made to meet this requirements such as inertial slider, inchworm, magnetic levitation stage etc [1][2][3]. In the precision sample measurement applications (STM, AFM, TEM, SEM), the positioning stability is also an important design consideration[4]. To meet these requirements a nanopositioner is designed using inertial slider and inertial walking method. The resulted travel range is 50mm×50mm and positioning resolution is a few nanometers.

The inertial slider motion is caused simply by a saw-tooth-like periodic acceleration of a piezoelectric element and the inertia of the moving stage. The body can travel long distance comprised of many small steps (nanometer to microns) by the stick-slip effect between two contact solids. The inertial walking method has an advantage of stability which is accomplished by the supporting rod. Instead of the tube PZT, the three rods support the moving body and good stability is obtained. Inertial walking method has expansion and contraction of the tube PZT in the voltage input sequence which is somewhat different from inertial slider.

The new nanopositioner has simple structure and can be operated with either method and is always on the base surface by the three contact points.

Operating Principle

The designed nanopositioner consists of three-tube-PZT (sapphire ball at the one end of each tube), three supporting rods, moving body, mirror surface base (See Fig.1). The three rods and three PZTs are located at the vertex position of the hexagon which is the body hole shape. Simple operation can make stage have three to six degree-of-freedom motion. The three planar motion(\(X,Y,\theta\)) have unlimited motion range and nanometer(micro radian) resolution and in the other three DOF motion travel range is limited by the expansion of tube PZTs. Two operating methods, inertial slider and walking, can be adopted. Inertial slider operation is the one which is the same as conventional operation except for the complexity.
of the actuation and inertial walking method is the new one of which cycle is composed of the actuation of three tube PZTs along with expansion and contraction. When the body is stationary phase, it is on the base by the supporting rod. The second method can eliminate PZT drift problems and will show more stable position maintaining characteristic.

Figure 2 shows the two operating principles. The left column sequence is the inertial slider operation and the right column is the inertial walking. Inertial slider method can make motion by the stick-slip effect between contact surfaces, sapphire ball and mirror-surface, and the slip motion phase is shown in the second figure(left column) and the slip can be made by the deflection of the tube PZTs. The third figure shows the stick phase, thus motion occurring, of which acceleration is relatively low.

In the inertial walking method, at first, expansion of the PZTs occurs (the second figure in the right column), and the next, the body moves by the deflection to the right(the third figure). In the last sequence contraction and deflection are followed and actuation sequence is repeated.

The fig. 2 is one dimensional movement principle schematic but the planar 3-DOF motion can be obtained by extend one dimensional movement to the planar motion. Figure 3 shows the motion direction(by deflection) of the tube PZTs and when signal inputs are applied for each PZT to have direction as shown in the figure, translational and rotational motion can be obtained.

**Mechanical Design**

The size of the mirror-surface base is 100mm x 100mm and the material is stainless-steel with hard chrome plated. The moving body weighs about 150g and has dimension of 50mm×50mm×48mm. The tube PZT[5] is four segmented type and has maximum contraction of 6μm. The outer diameter is 6.35mm and inner diameter is 5.15mm with 30mm tube length. Therefore the maximum deflection is about 20μm.
Considering charge constants and mechanical Q, the PZT material is selected to have good waveform-input following characteristic. For the stability and desirable inertial motion, a sapphire ball (6mm diameter), which has high hardness, is attached to the end of the tube PZT by the glue (Epoxy). Also the supporting rod has a hard steel ball at it’s end.

**Electrical Design**

The tube PZT has a 500V maximum voltage input and the actuating waveform frequency is in the range of a few kHz. Therefore 15 channel (12 for outer electrode and 3 for inner electrode) PZT driver which has at least 10khz bandwidth is needed and must not have nonlinear characteristic as possible such as signal distortion. PA88 [6] op-amp is used for high voltage amplification and about 30khz bandwidth and negligible distortions are obtained with designed driver.

For generating waveform signals, PC-based waveform generators are adopted [7] and it can generate signals at the rate of 1Msamples/sec.

**Discussion**

A multi-DOF nanopositioner was developed, having long moving range and nanometer resolution, and it
has simple design concept and operation methods. It is also operated by either of the two methods (inertial slider and inertial walking). Mechanical and electrical components was developed and experiments are being processed. Using laser interferometer and capacitive sensors, the control experiments of the nanopositioner are in the recent work.

![Image of nanopositioner](image)

Fig. 4  Picture of the multi-axis nanopositioner

References

[6]  PA88, Apex Microtechnology, 5890 N. Shannon Road, Tucson AZ 85741-5230