Design, Modeling and Analysis of a Novel Piezoactuated XY Nanopositioner Supporting Beamline Optical Scanning

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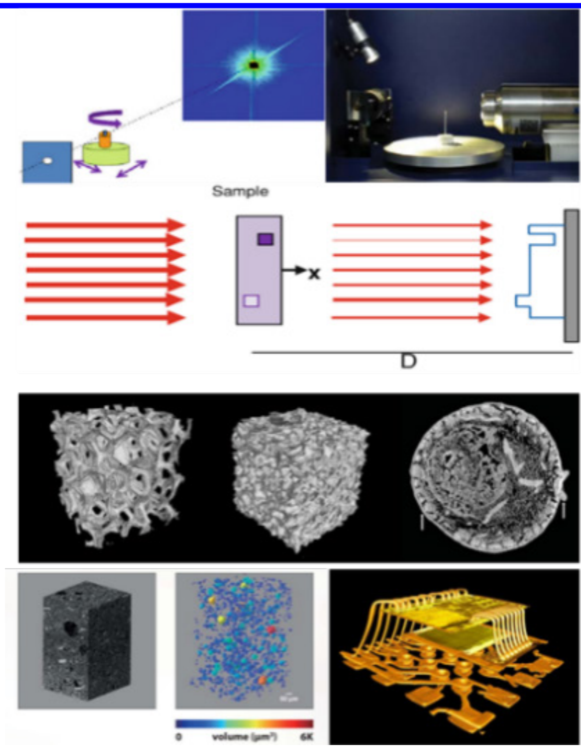
MEDSI BEIJING

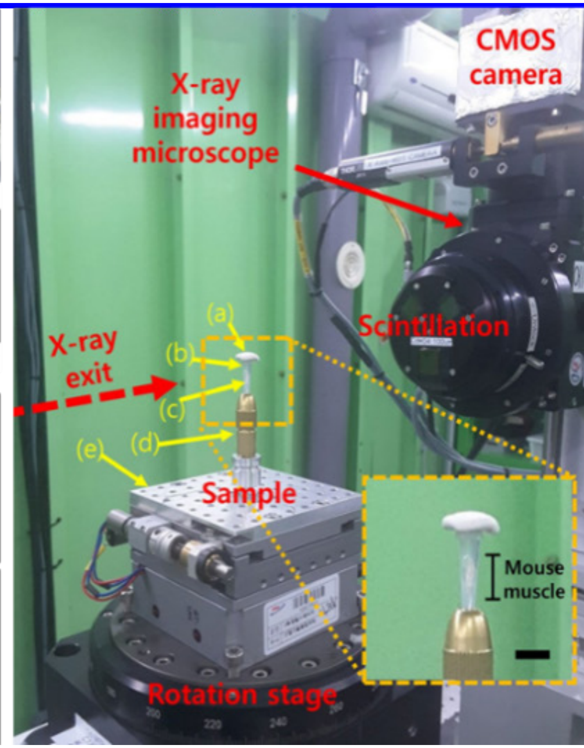
Outline

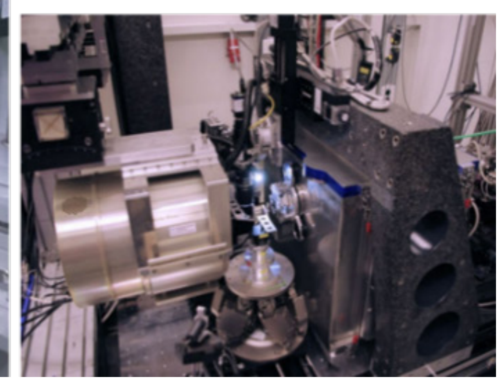
- **Background**
- **Design of the XY Nanopositioning Platform**
- **Simulated Analysis**
- **Conclusions and Future Work**

Background

- The advantages of four generation of light sources —— Nanoscale spatial resolution
- High precision sample attitude adjustment system——Nanoscale positioning accuracy, High dynamic scanning, Multi-degree-of-freedom collaboration







Key component：High dynamic piezoelectric nanomotion system

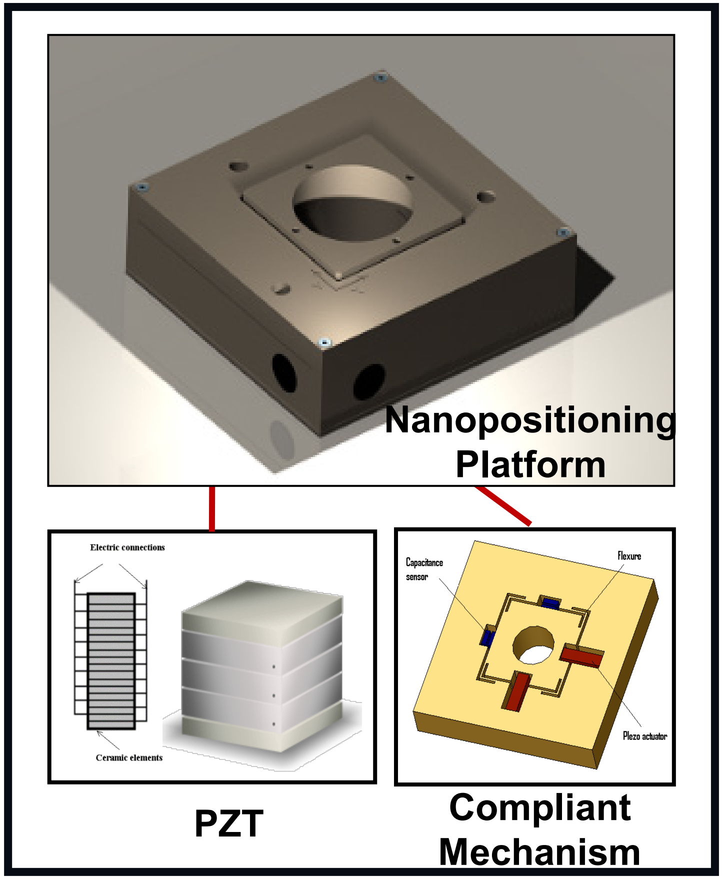
Background

➢ **Compliant Mechanism**

- **No friction**
- **No backlash**
- **No wear**
- **Transmitting motion, force and energy by elastic deformations**

➢ **Piezoelectric Actuator**

- **High stiffness**
- **High bandwidth**
- **Nanometer resolution**
- **Fast response time**



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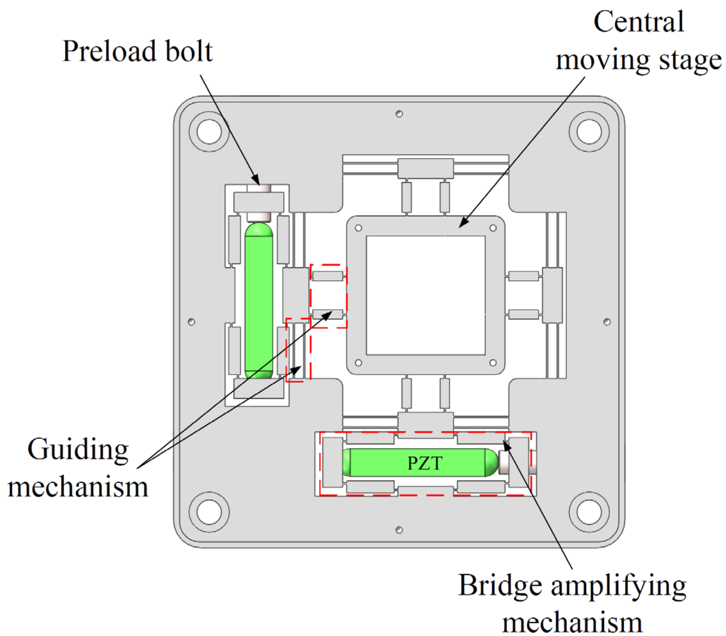
Design of the XY Nanopositioning Platform



Schematic diagram of the XY positioning platform.

- Bridge amplifying mechanism

  Achieve greater output displacement and compact structure

- Hollow structure

  Convenient for optical scanning experiments

- Two sets of guiding mechanisms

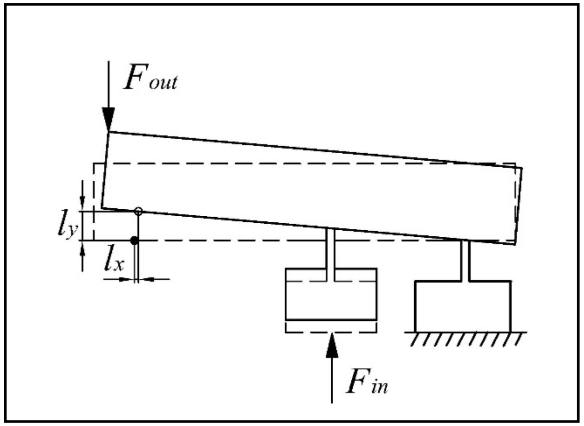
  Ensuring optimal platform stiffness

- Symmetrical design

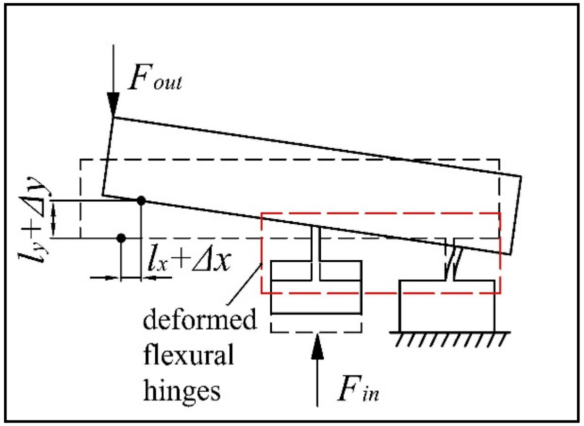
  Enhance platform decoupling capabilities

Design of the XY Nanopositioning Platform

Compliance modelling of flexure hinges

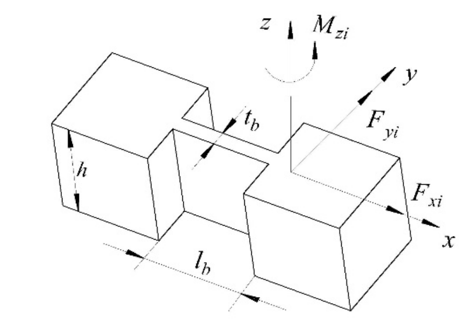


The ideal output PRB modal



The output considering the deformation of flexural hinges

- The stiffness and deformation of flexure hinges in all directions will influence the performance of the platform. Like the compress and bending of hinges.
- The deformation of flexure hinges are taken into account through elastic beam theory.



Prismatic beam hinge

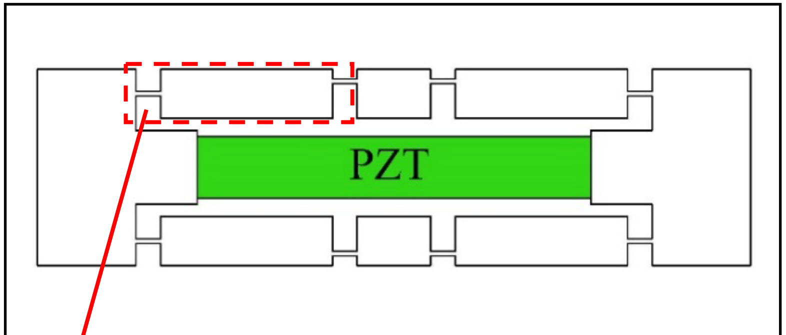
Regarded as a cantilever beam

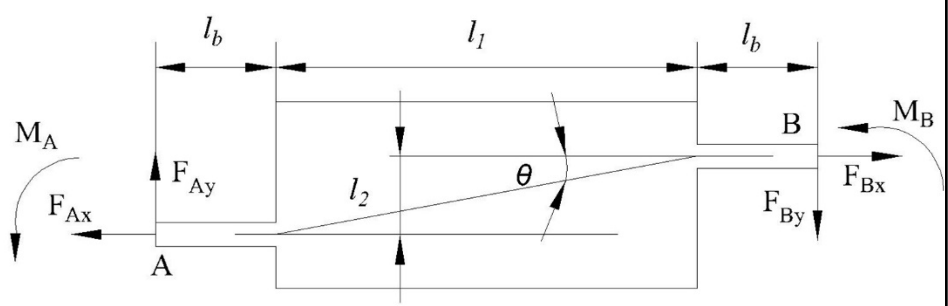
Elastic beam theory

$$\begin{bmatrix} \delta x \\ \delta y \\ \delta \theta \end{bmatrix} = \begin{bmatrix} C_{11} & 0 & 0 \\ 0 & C_{22} & C_{23} \\ 0 & C_{32} & C_{33} \end{bmatrix} \begin{bmatrix} F_x \\ F_y \\ M_z \end{bmatrix}$$

Design of the XY Nanopositioning Platform

Compliance modelling of bridge amplifying mechanism





Force condition

1/4 of the bridge amplifying mechanism

Bridge amplifying mechanism

Boundary conditions

$\sum F = 0; \quad \sum M = 0$

$F = -F'$

Elastic beam theory

$\delta = C \cdot F$

***C* is compliance matrix**

Input displacement：

$$\Delta X = \left(c_{11} + \frac{l_2^2 c_{33}}{4}\right) F_{pzt} + \left(\frac{l_2 c_{32}}{2} = \frac{l_2 l_1 c_{33}}{4}\right) F_s$$

Output displacement：

$$\Delta Y = \left(\frac{l_2 c_{23}}{2} + \frac{l_1 l_2 c_{33}}{4}\right) F_{pzt} + \left(c_{22} + \frac{l_1 c_{32}}{2} - \frac{l_1 c_{23}}{2} - \frac{l_1^2 c_{33}}{4}\right) F_s$$

$$R_a = \frac{9 l_2 \left(l_b + l_1\right) F_{pzt} + \left[4 l_b^2 + 6 t_b^2 \left(1 + \mu\right) - 9 l_1^2\right] F_s}{3\left(t_b^2 + 3 l_2^2\right) F_{pzt} + 9 l_2 \left(l_b - l_1\right) F_s}$$

μ is the Poisson ratio of the material.

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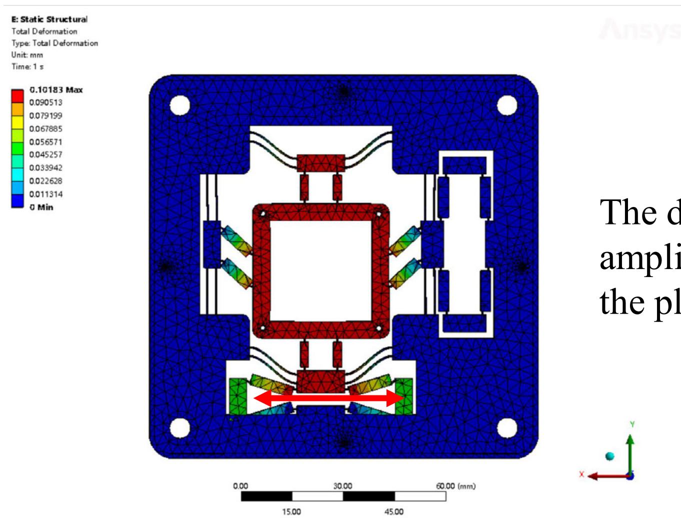
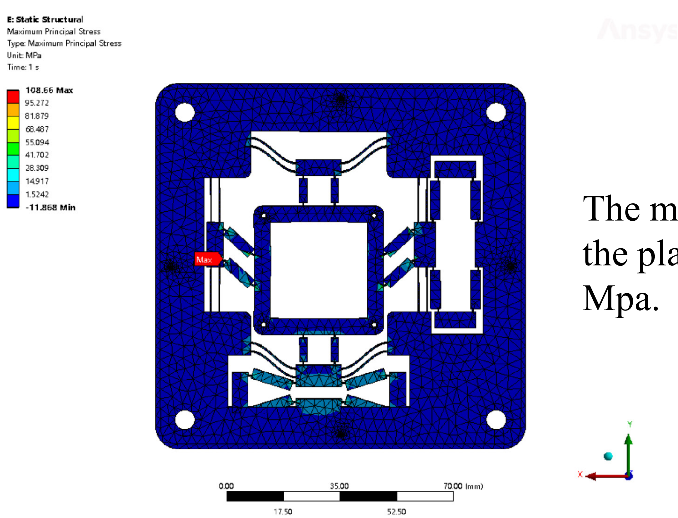
Simulated Analysis

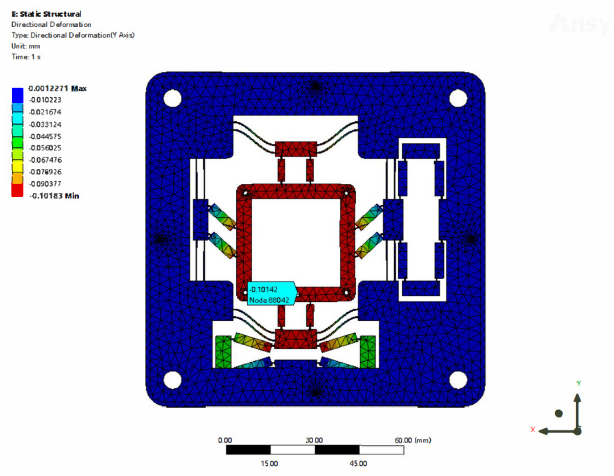
Static Simulation



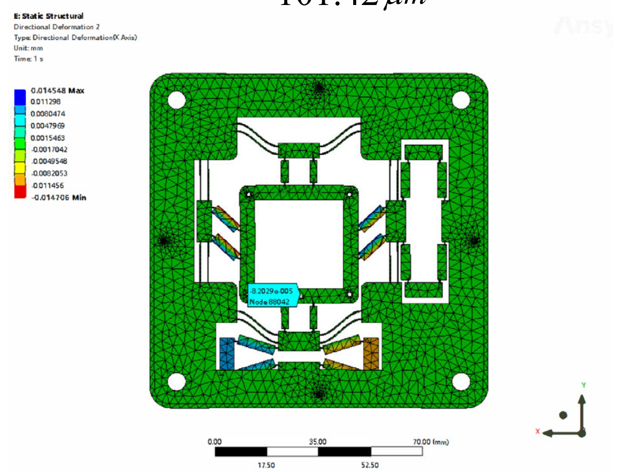
The displacement amplification ratio of the platform is 10.14.



The maximum stress of the platform is 108.66 Mpa.



101.42 μm

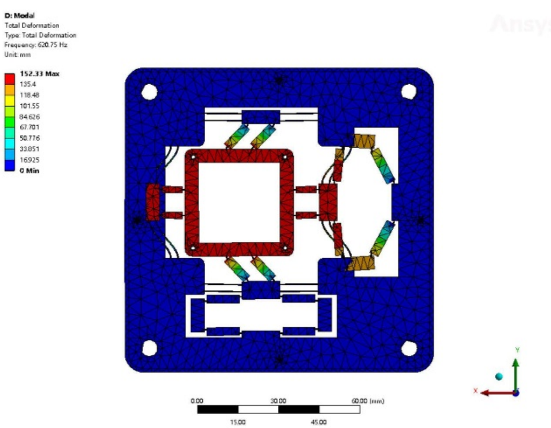


0.08 μm

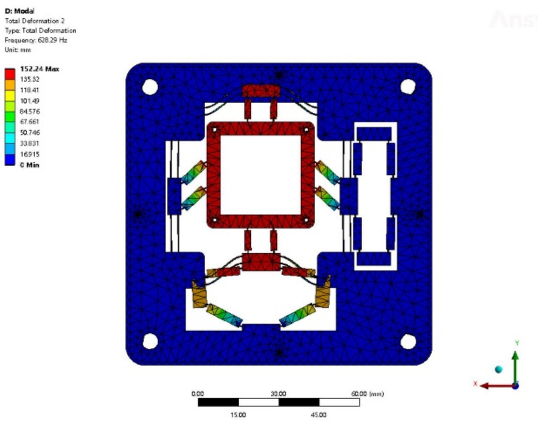
Coupling is only 0.07%.

Simulated Analysis

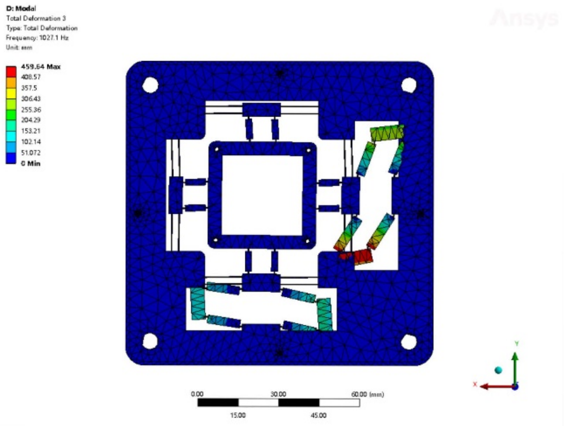
Modal Analysis



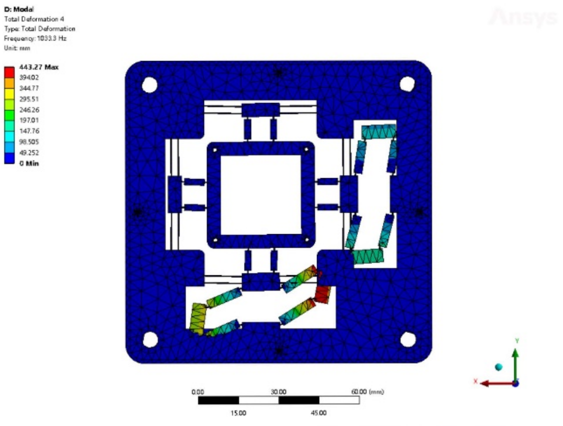
620.7Hz



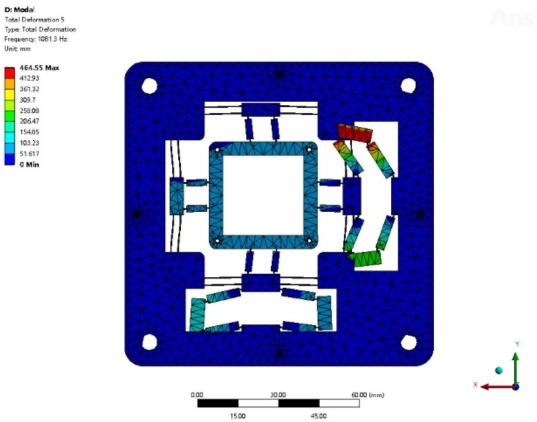
628.2Hz



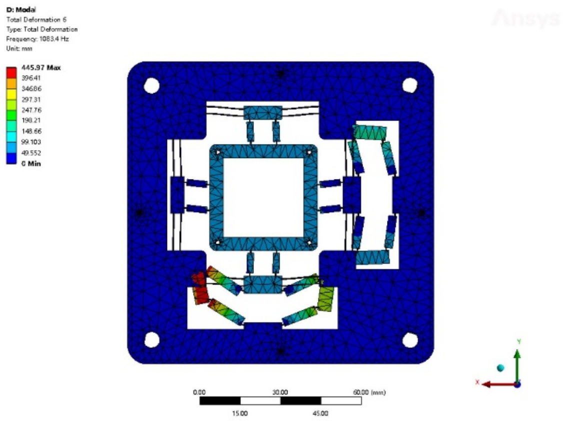
1027.1Hz



1033.3Hz



1081.3Hz



1083.4Hz

Excellent dynamic characteristics

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Conclusion

Conclusion:

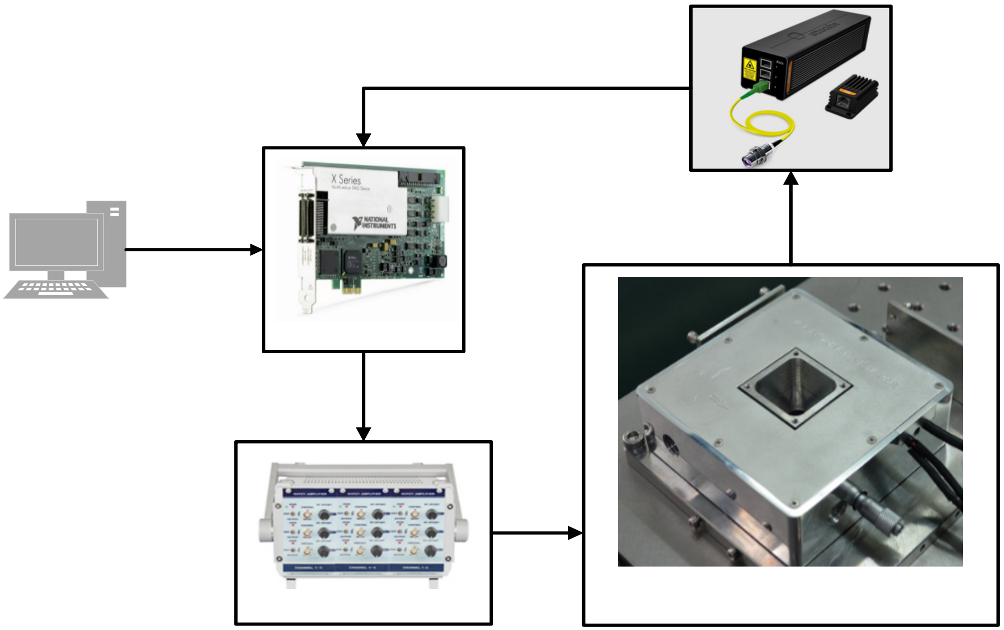
- An XY piezo-driven nano-positioning platform with a hollow structure for optical scanning is proposed.
- An analytical model is established based on elastic beam theory and the performance of the platform is verified by numerical simulations.
- The displacement amplification ratio of the platform reaches 10.14. And the first order natural frequency reaches 620.7Hz with excellent dynamic characteristics.

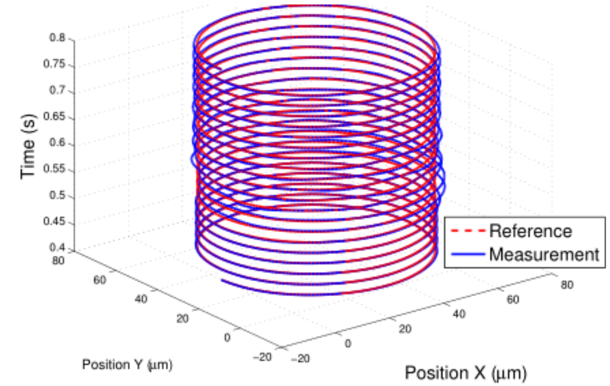
Future work:

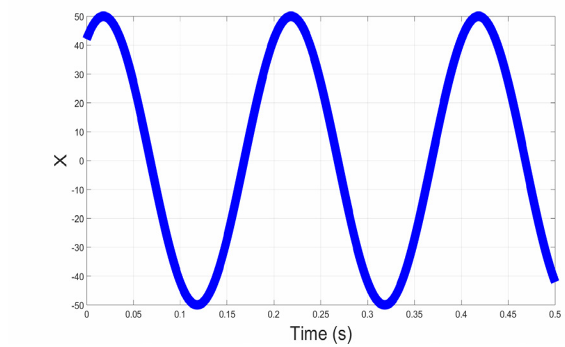
The feedback sensor of displacement will be designed and integrated. The precise control will be implemented.

Future work

Future work in detail





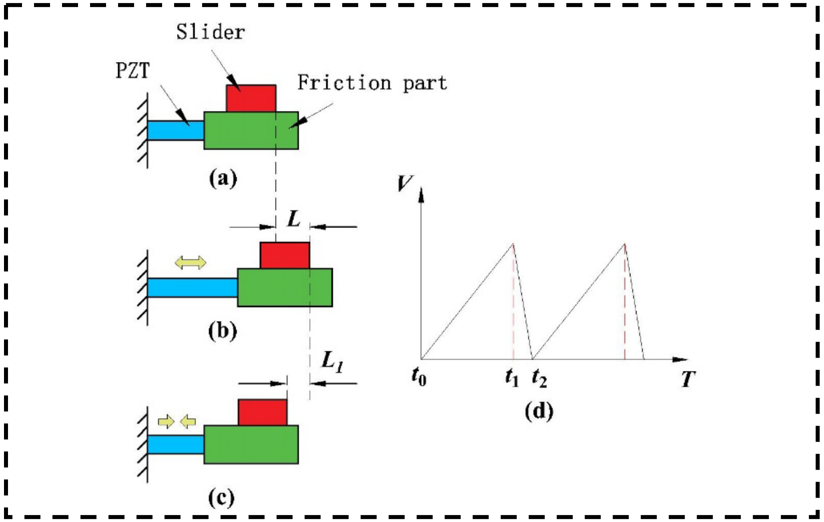


Position sensor will be installed + A real-time control system will be built + Control algorithm needs to be optimized → Achieve high dynamic positioning and scanning of the platform

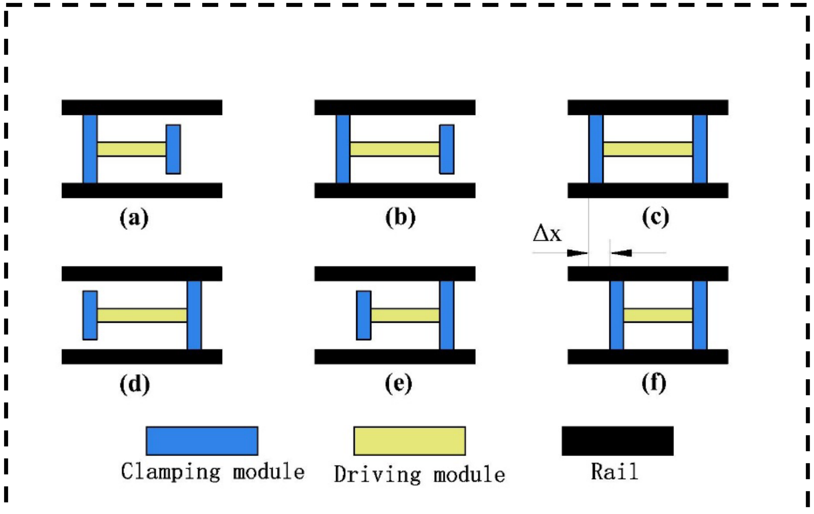
Future work

Future work development—Cross-scale motion

Stick-slip motion principle

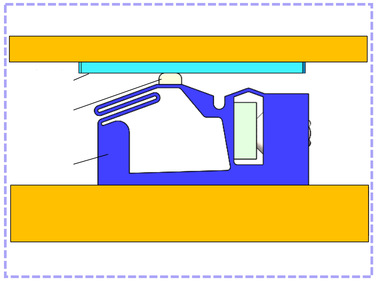


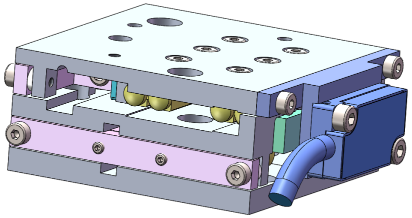
Inchworm motion principle



- Simple structure, fast moving speed, simple control method
- ◆ Regression displacement

- Precise single step length, greater output force
- ◆ Complex structure, Complex control sequence





Large load Z-moving platform

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Thank you!