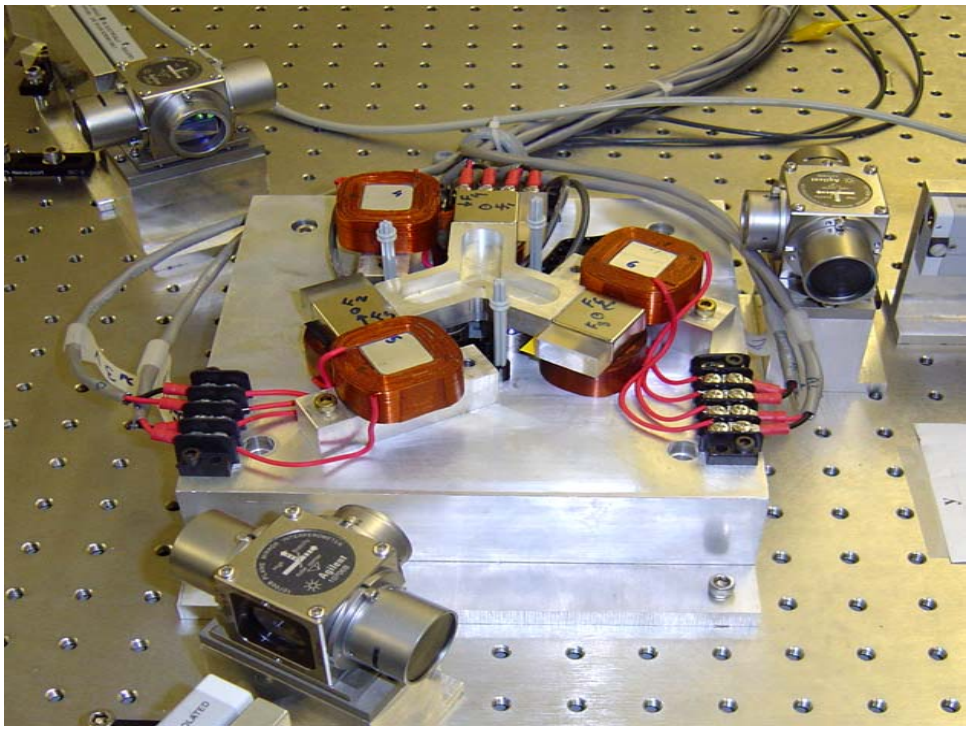
Multi-axis maglev positioner with high resolution over large travel range



Won-jong Kim
wjkim@tamu.edu
and
Shobhit Verma
shobhit.verma@gmail.com

Presented by:
Huzefa Shakir
huzefa@tamu.edu

Texas A&M University

ASME International
Mechanical Engineering Congress & Exposition
Orlando FL, November 5-11 2005

Presentation overview

- Introduction
- Instrumentation
- Actuation
- Dynamic modeling and control
- Experimental results

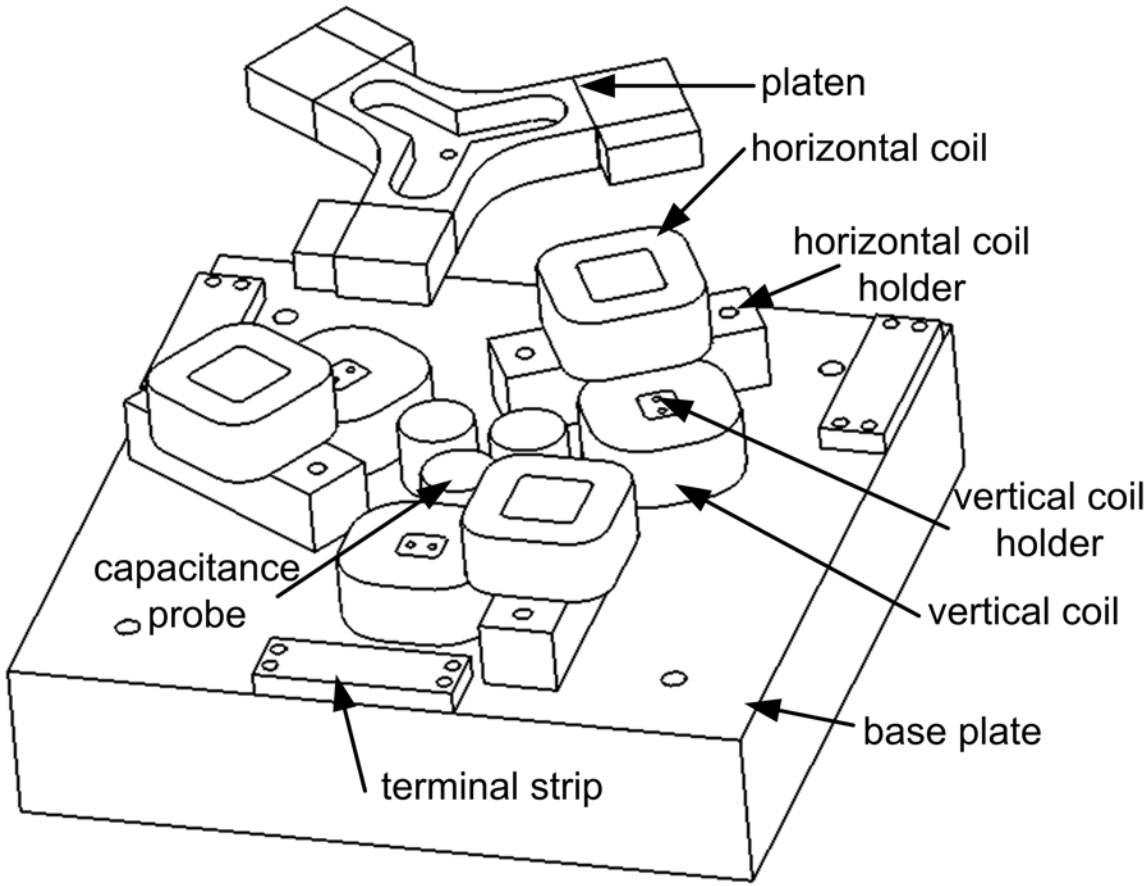
Introduction

Maglev technology

- No friction, backlash and hysteresis
- No requirement of lubricant and bearings
- Fast response
- Multi-DOF motion with simple structure
- Ideal for clean-room environment

Introduction

Exploded view of the maglev stage system



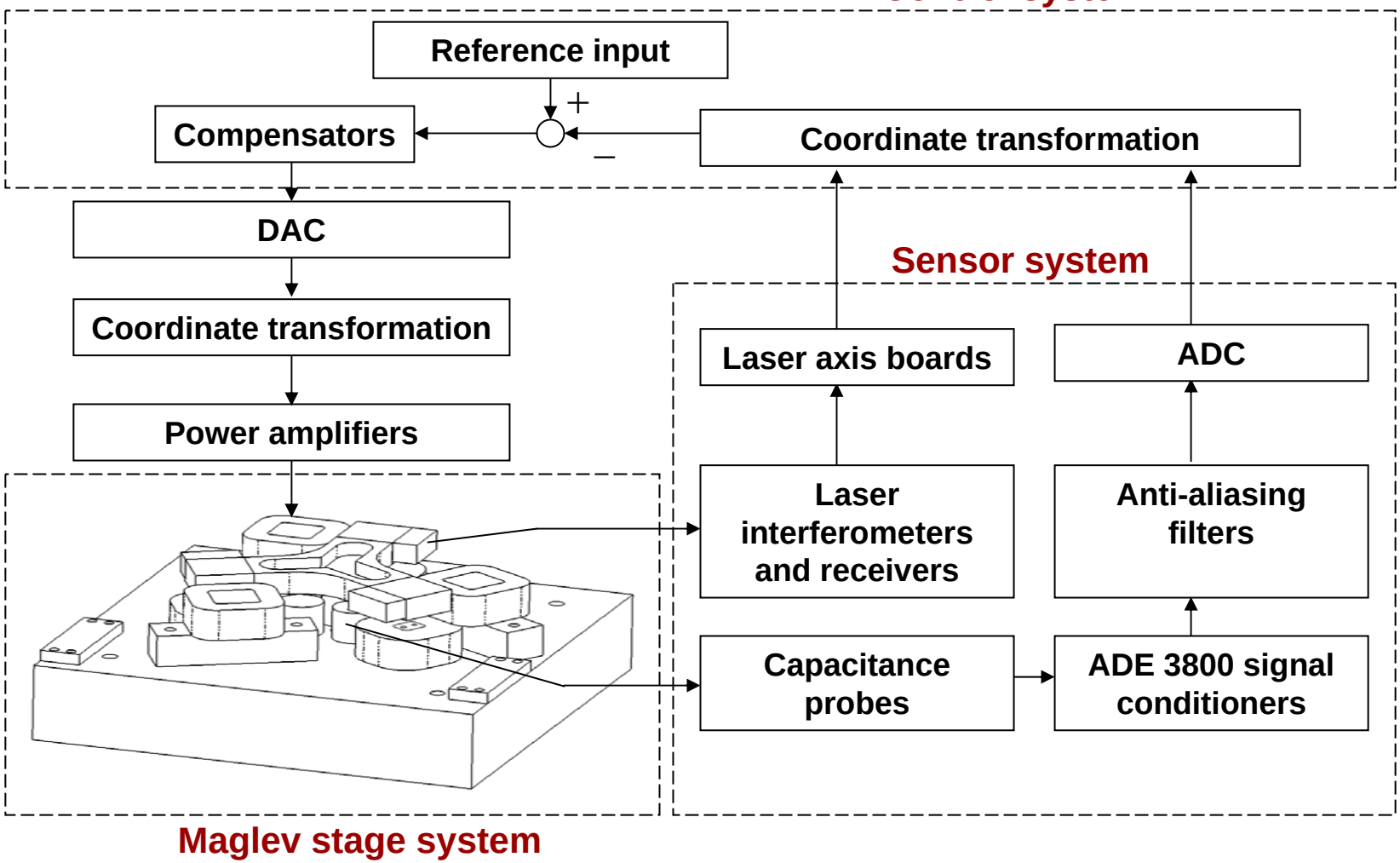
Introduction

Specifications

➢ **Motion capability:**	**6-DOF**
➢ **Positioning resolution:**	**3 nm rms**
➢ **Angular resolution:**	**100 nrad**
➢ **Travel range:**	**5 mm translation in *x* & *y*** **500-µm in *z*** **3.5-mrad rotation**
➢ **Light moving part:**	**0.267 kg**
➢ **Maximum acceleration:**	**2.5 *g* Horizontal in motion** **8 *g* in vertical motion**
➢ **Maximum payload:**	**2 kg**

Instrumentation

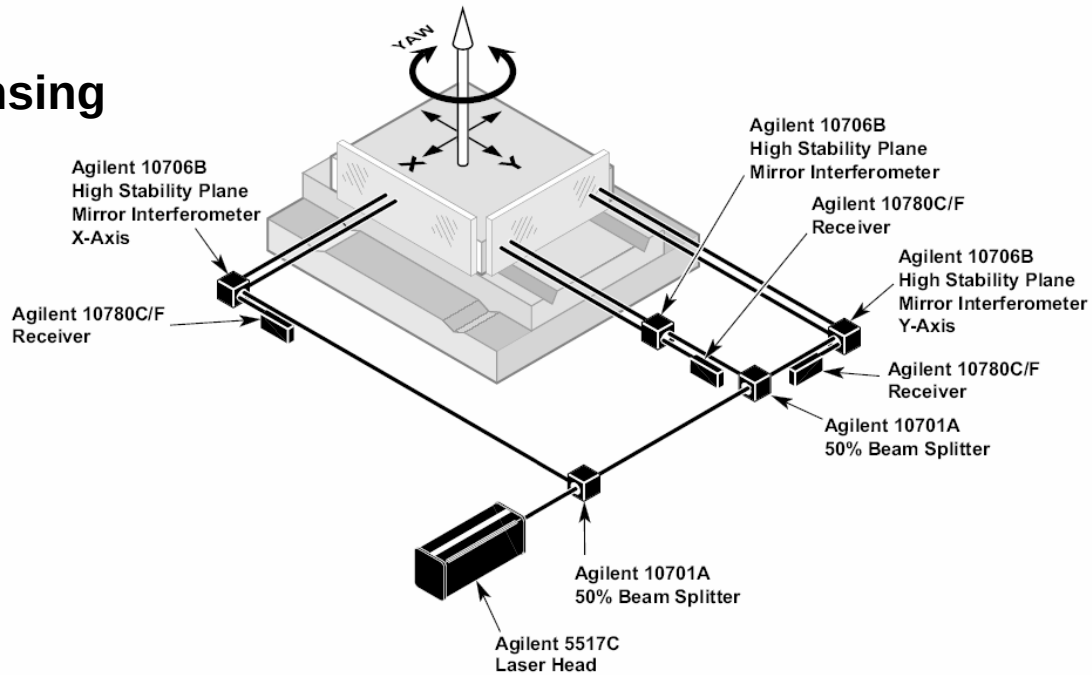
Instrumentation structure



Instrumentation

Laser Interferometry

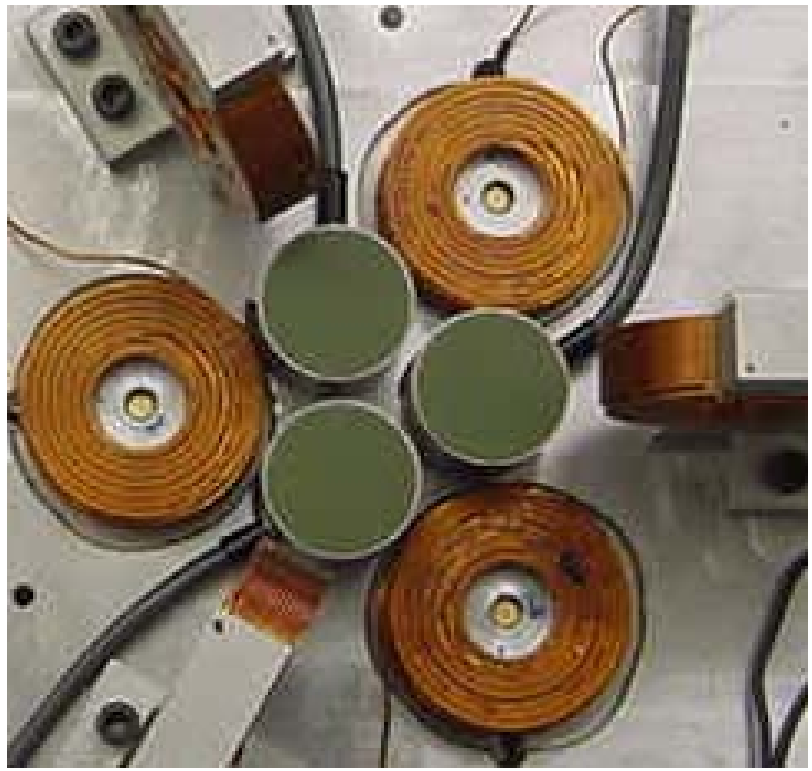
- Horizontal motion sensing
- 632 nm HeNe Laser
- 0.6 nm resolution
- 40-m sensing range
- Up to 0.5 m/s velocity



Instrumentation

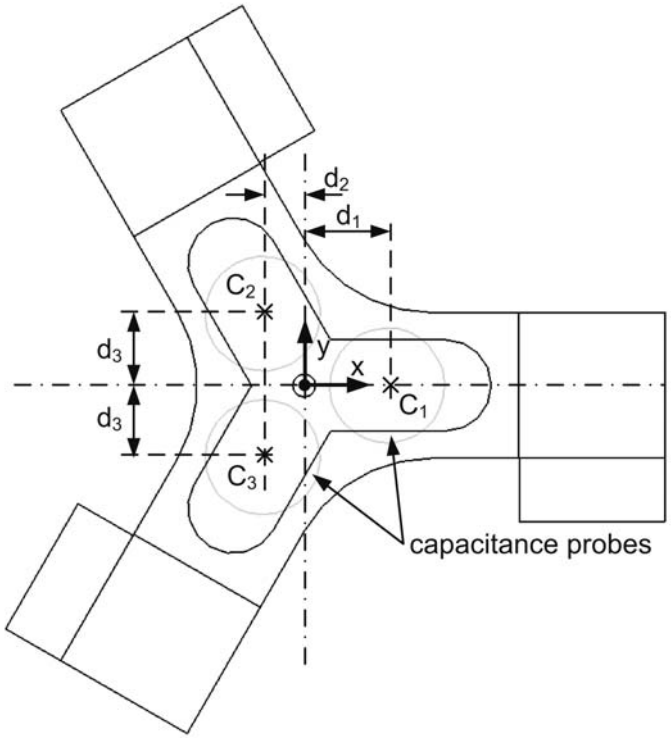
Capacitance probes

- Vertical motion sensing
- 500 μm sensing range
- –5 to +5 V sensor output
- Absolute position sensing

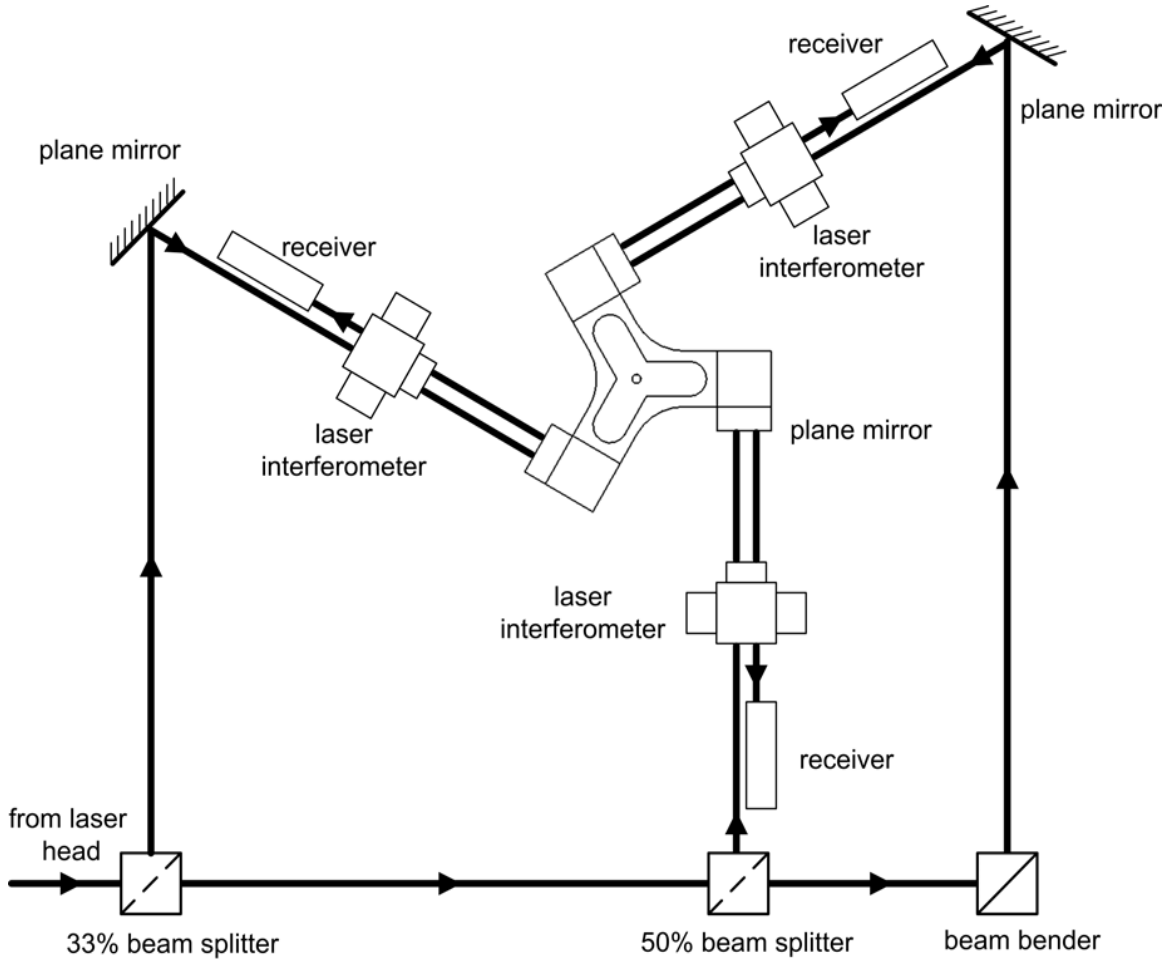


Instrumentation

Sensor placement



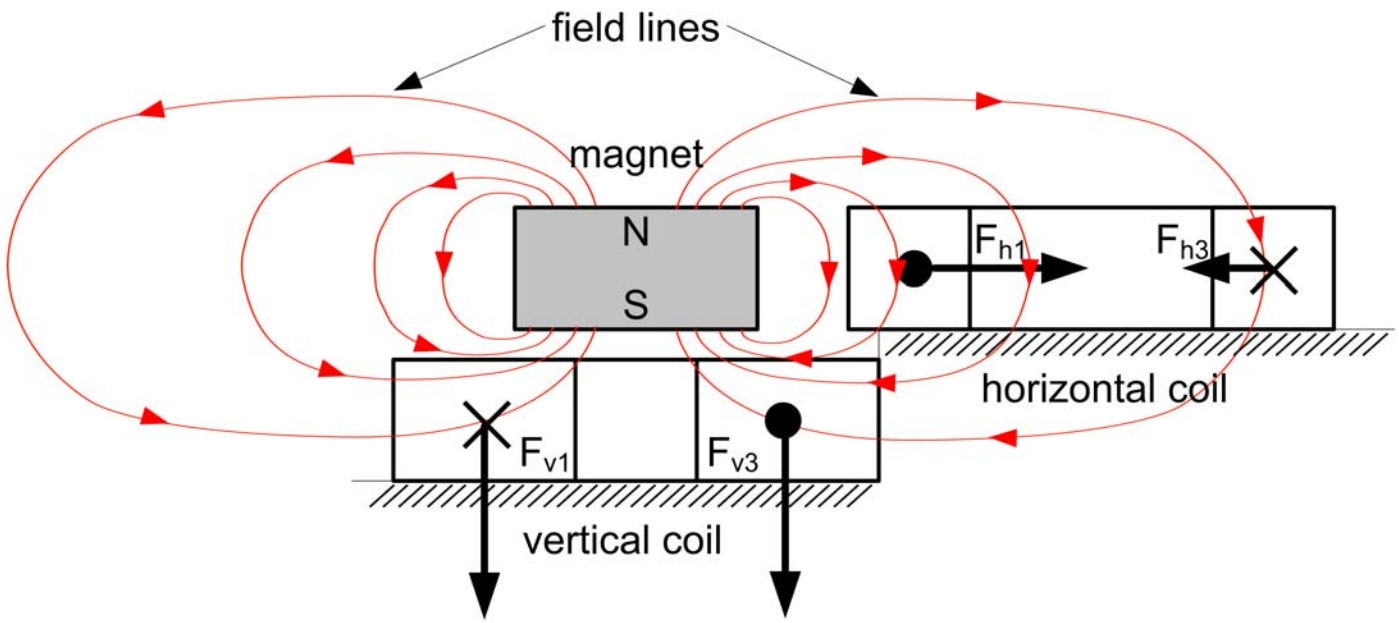
Vertical motion sensing



Horizontal motion sensing

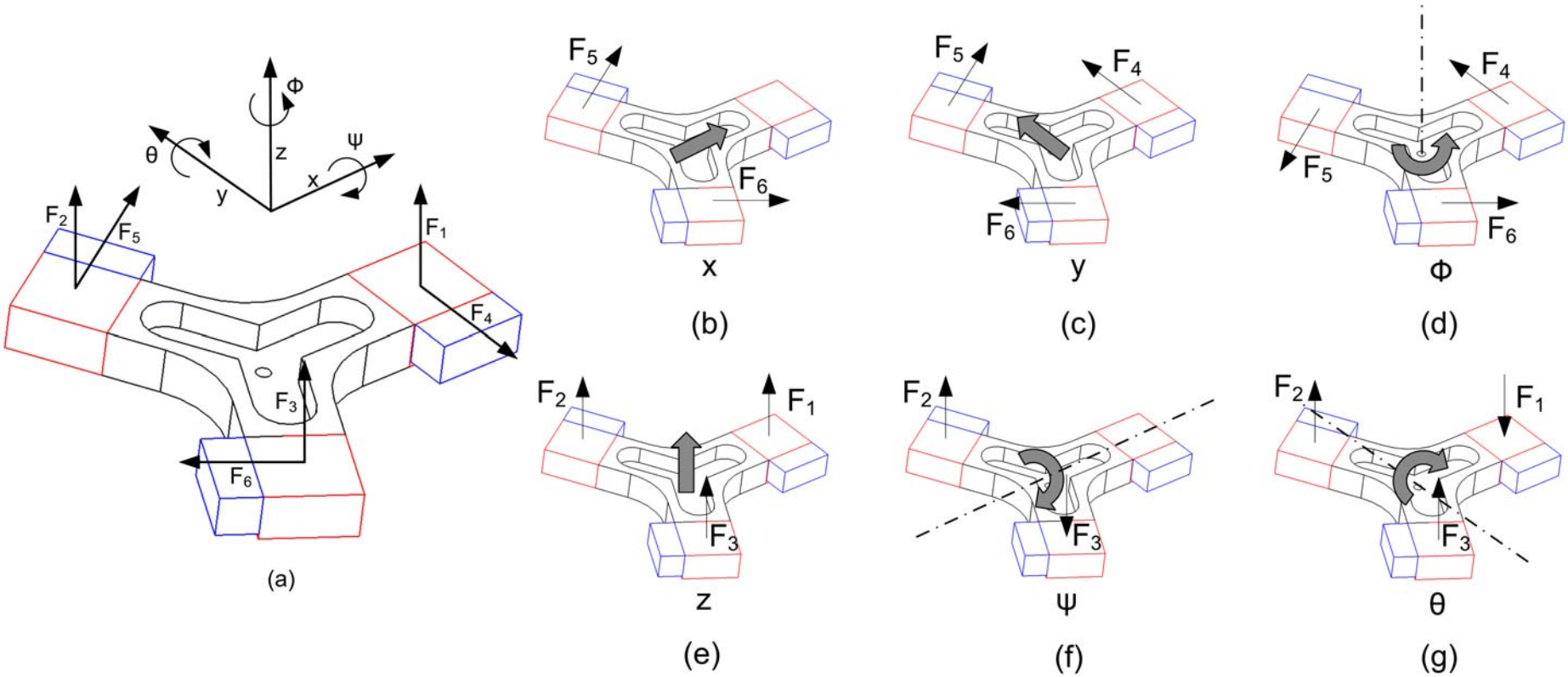
Actuation

Novel dual-force actuation scheme



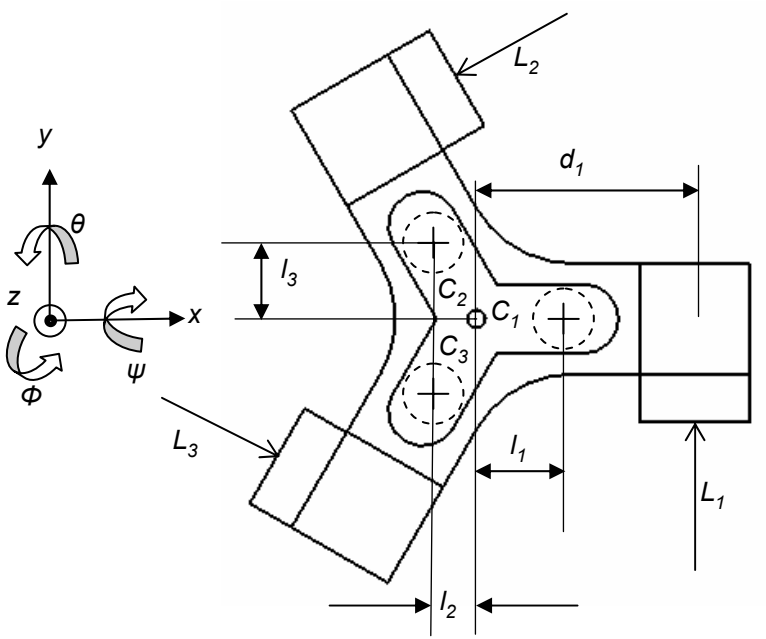
Actuation

Working principle



Dynamic modeling and control

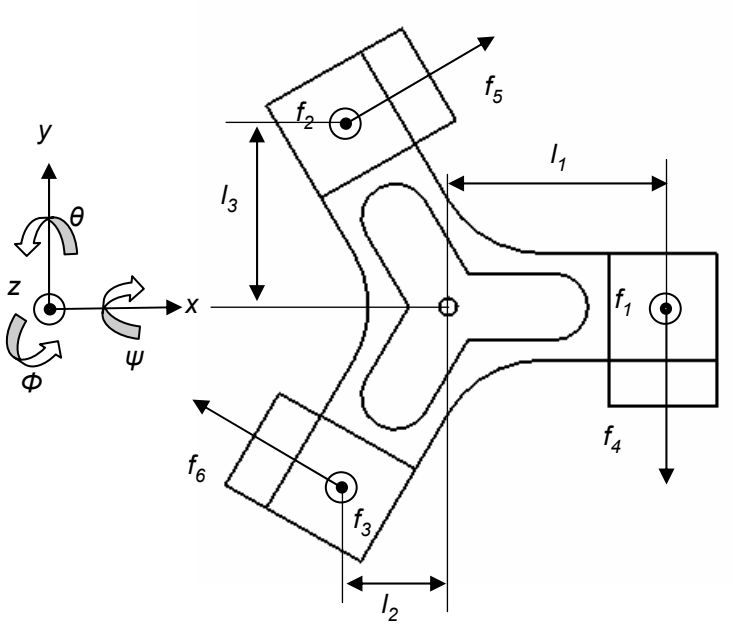
Modal displacement transformation



$$\begin{bmatrix} L_1 \\ L_2 \\ L_3 \\ C_1 \\ C_2 \\ C_3 \end{bmatrix} = \begin{bmatrix} 0 & -1 & -d_1 & 0 & 0 & 0 \\ \cos 30^\circ & \cos 60^\circ & -d_1 & 0 & 0 & 0 \\ -\cos 30^\circ & \cos 60^\circ & -d_1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & -l_1 \\ 0 & 0 & 0 & 1 & l_3 & l_2 \\ 0 & 0 & 0 & 1 & -l_3 & l_2 \end{bmatrix} \begin{bmatrix} x \\ y \\ \phi \\ z \\ \psi \\ \theta \end{bmatrix}$$

Dynamic modeling and control

Modal force transformation



$$\begin{bmatrix} f_x \\ f_y \\ \tau_\phi \\ f_z \\ \tau_\psi \\ \tau_\theta \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & \cos 30^\circ & -\cos 30^\circ \\ 0 & 0 & 0 & -1 & \sin 30^\circ & \sin 30^\circ \\ 0 & 0 & 0 & -l_1 & -l_1 & -l_1 \\ 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & l_3 & -l_3 & 0 & 0 & 0 \\ -l_1 & l_2 & l_2 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \\ f_5 \\ f_6 \end{bmatrix}$$

Dynamic modeling and control

System modeling

Pure-mass model: $f = m\ddot{x}$ $\quad T = I\ddot{\theta}$

$$m = 0.267 \ \boldsymbol{kg}$$

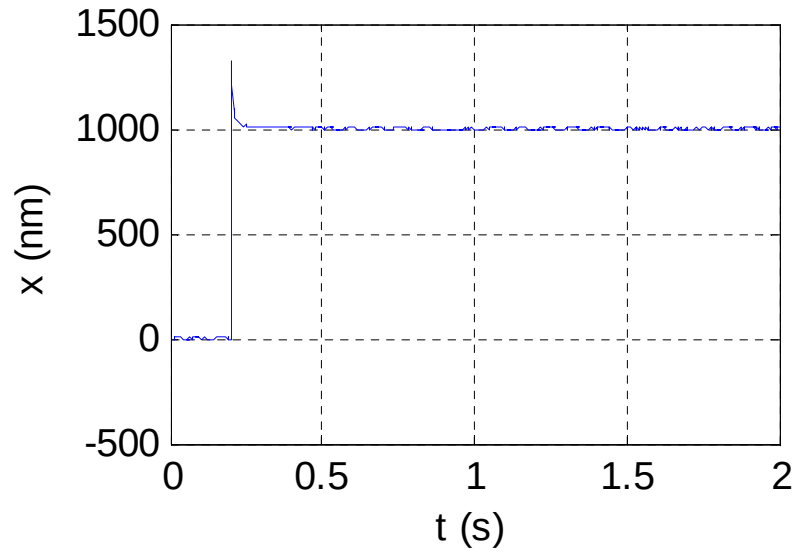
$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix} = \begin{bmatrix} 340.37 & 0 & 0 \\ 0 & 340.37 & 0 \\ 0 & 0 & 653.61 \end{bmatrix} \times 10^{-6} \ \boldsymbol{kg\text{-}m^2}$$

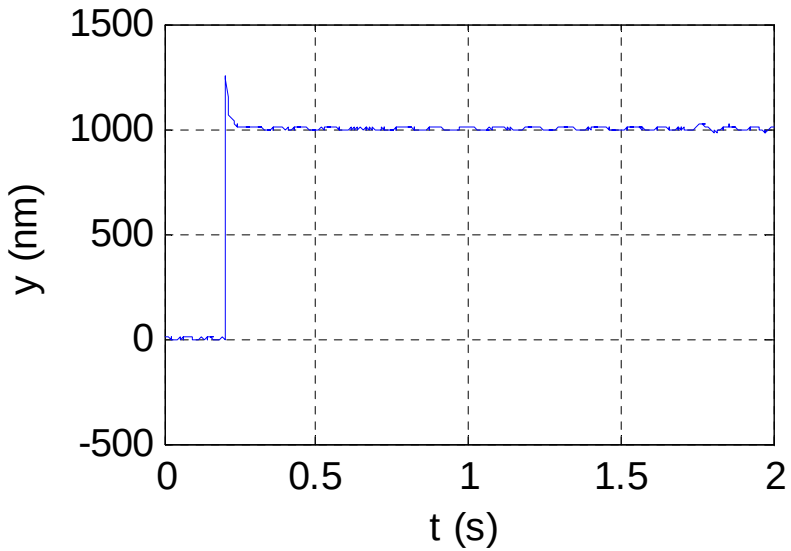
$$\frac{X(s)}{F(s)} = \frac{1}{ms^2} \qquad \frac{\Theta(s)}{T(s)} = \frac{1}{Is^2}$$

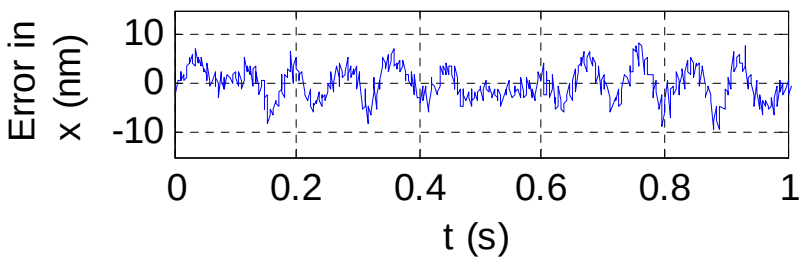
Dynamic modeling and control

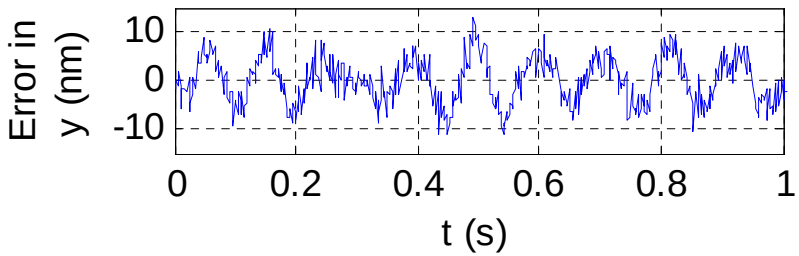
Horizontal motion control

$$G_{x,y,\phi}(s) = \frac{K(s+259.8)(s+50.68)}{s(s+1690)}$$





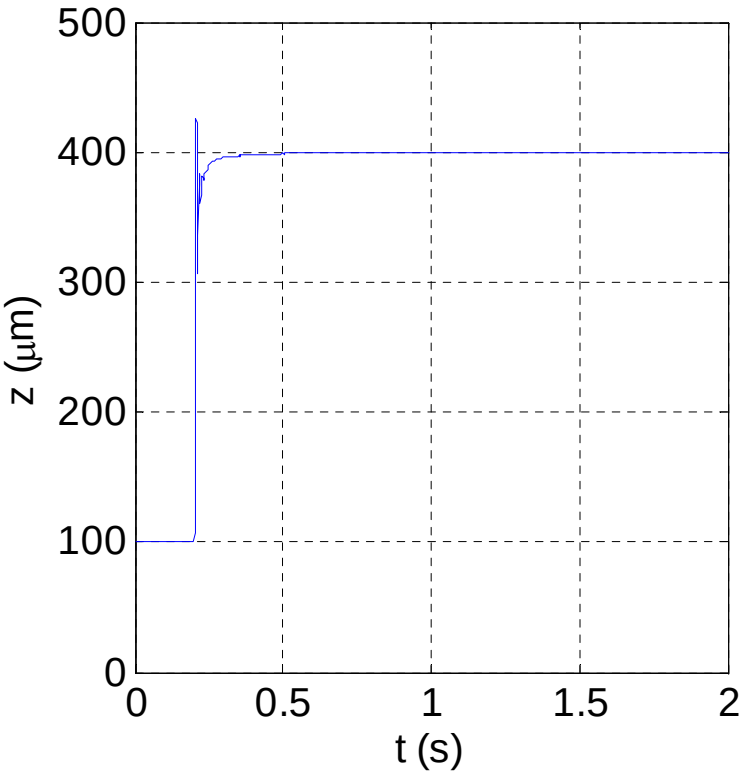




Dynamic modeling and control

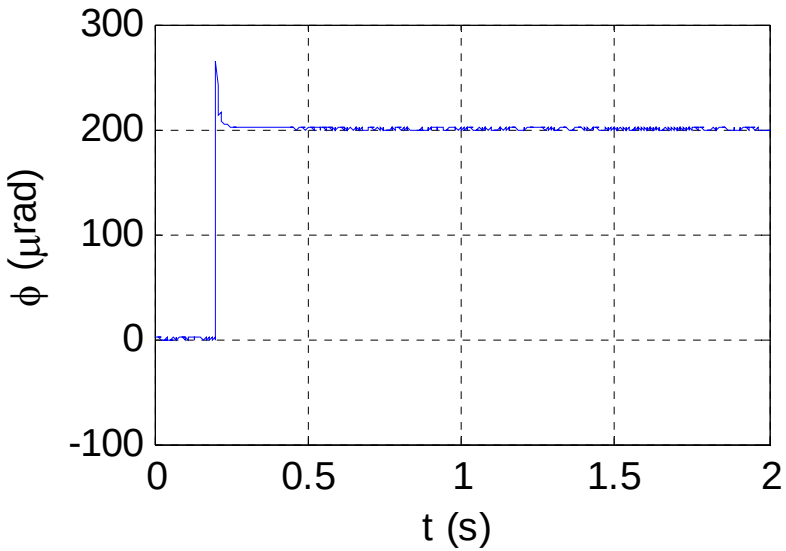
Vertical motion control

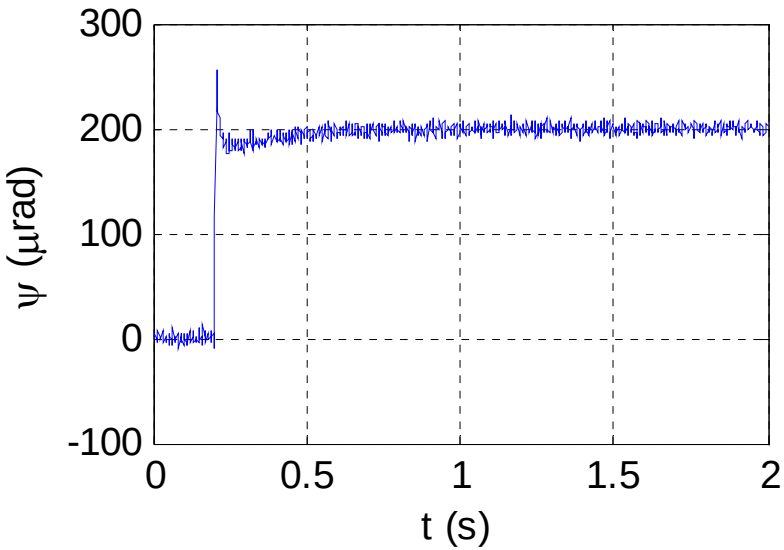
$$G_{z,\psi,\theta}(s) = \frac{K(s+57.47)(s+6.271)}{s(s+2103)}$$

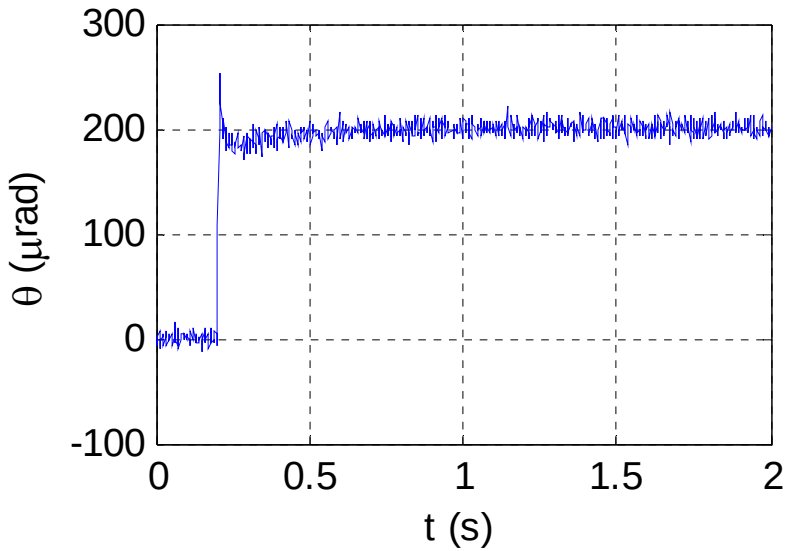


Dynamic modeling and control

Rotational motion control

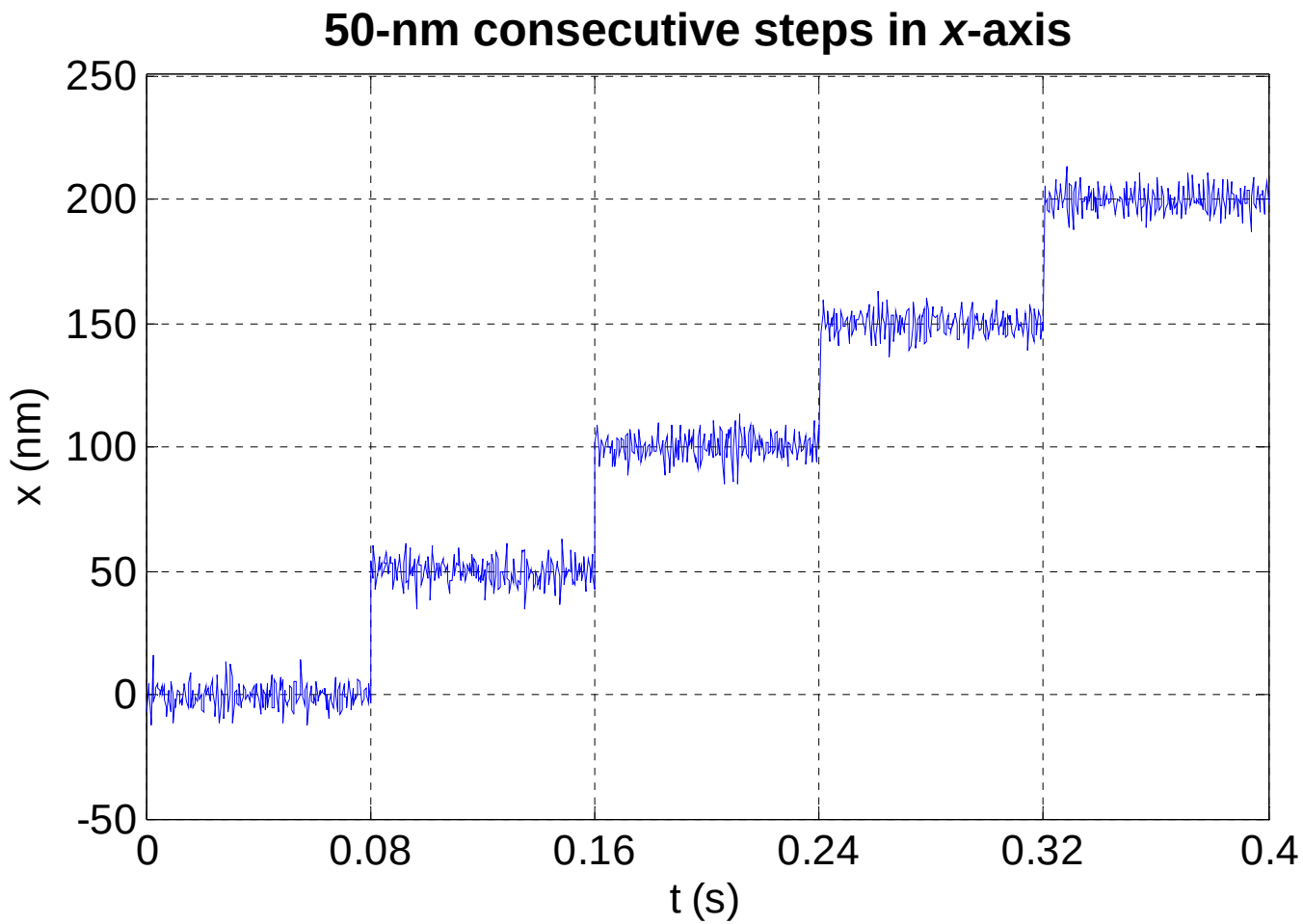






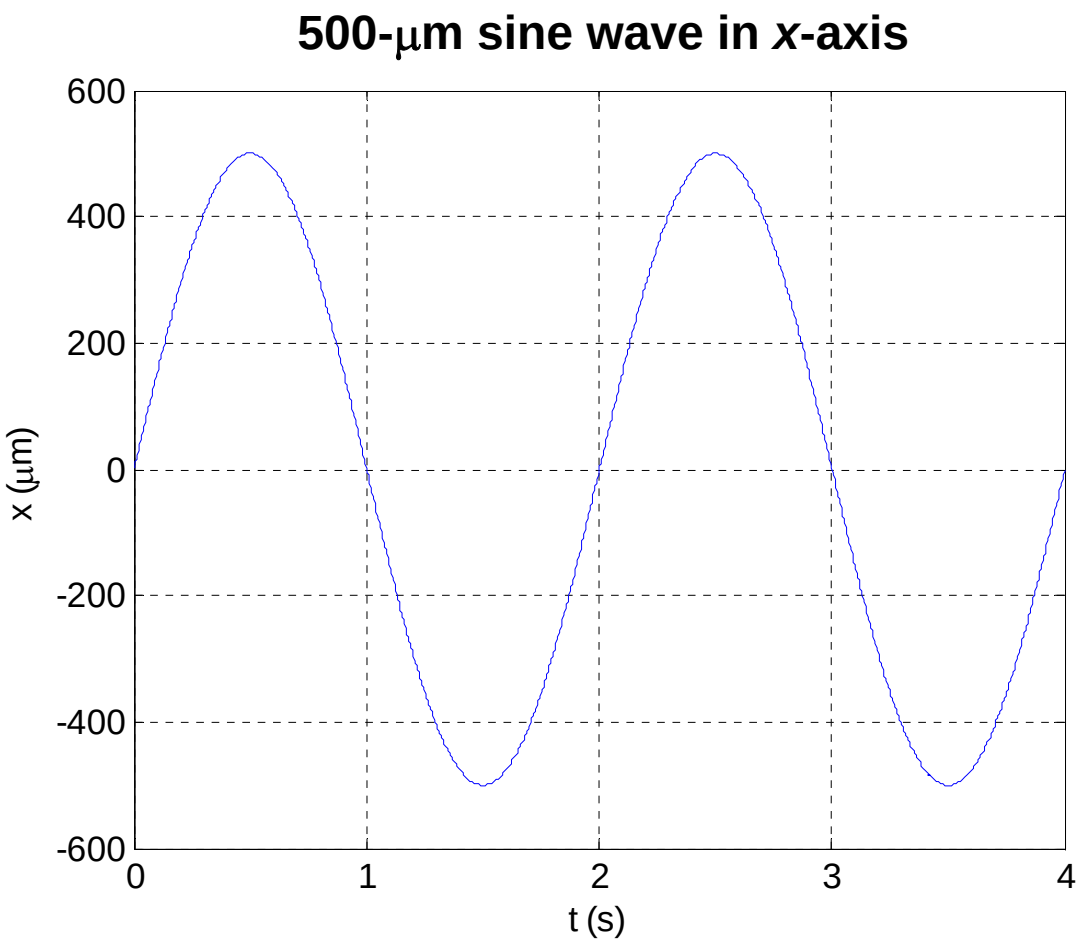
Experimental results

Precision positioning



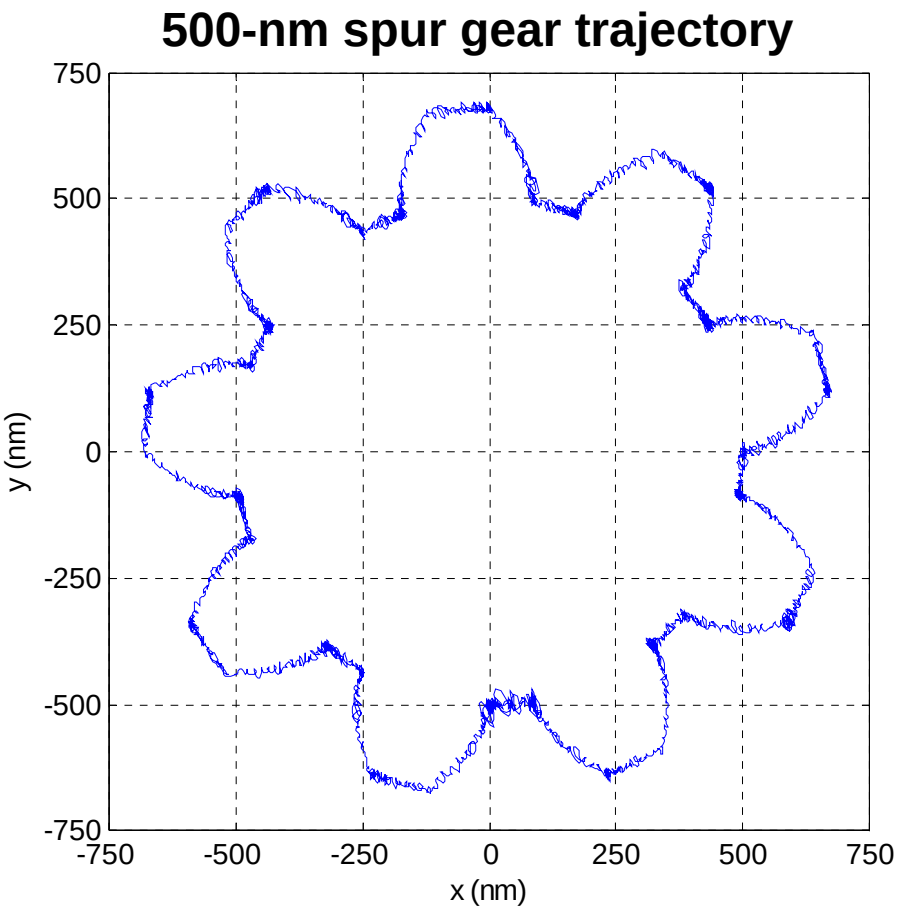
Experimental results

Precision positioning



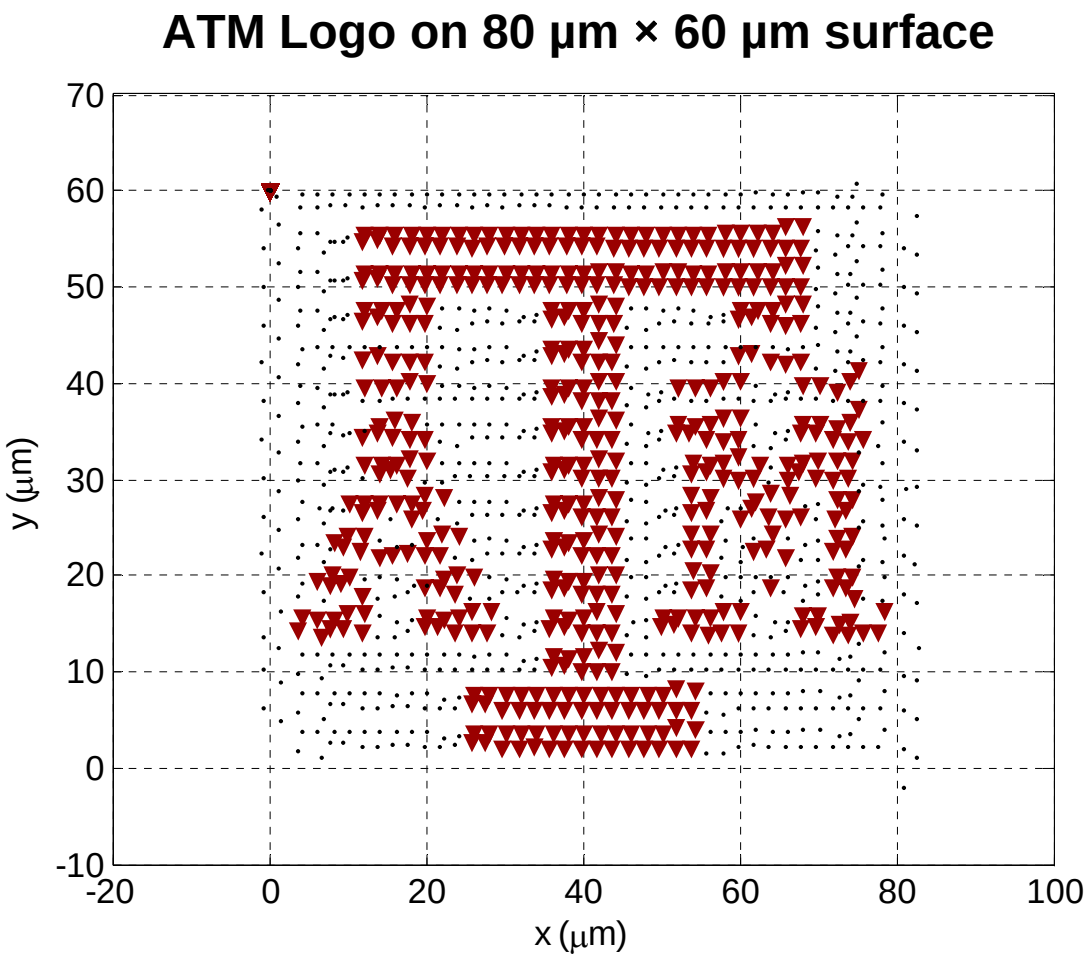
Experimental results

Trajectory tracking



Experimental results

Indentation



Experimental results

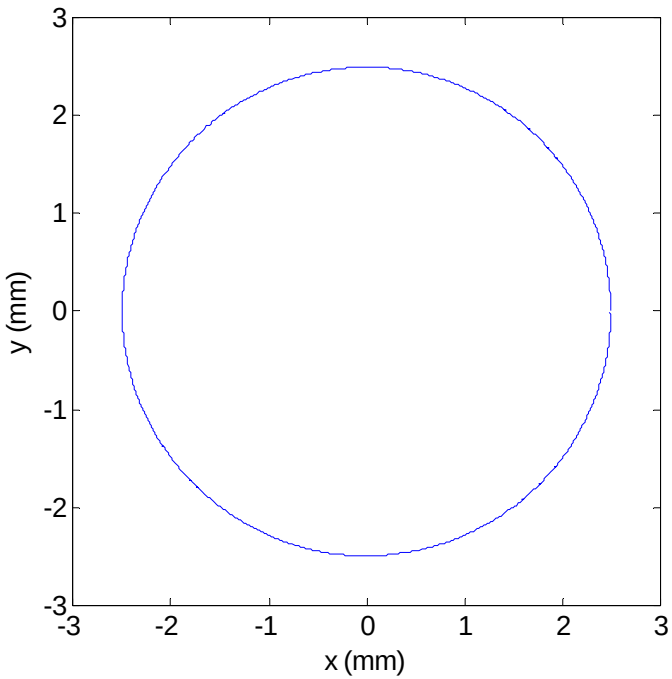
Positioning in large travel range

Large motions in the *x*- and *y*-axes

Experimental results

Positioning in large travel range

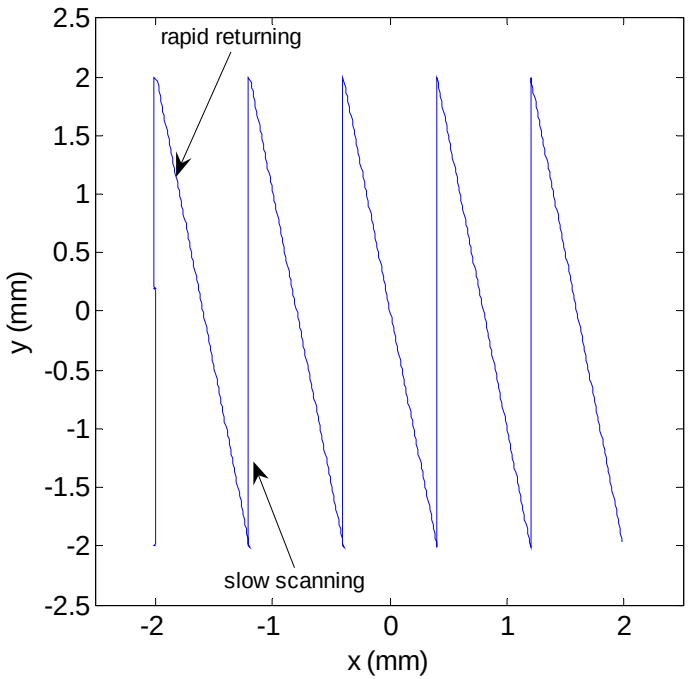
5-mm diameter circle



Experimental results

Positioning in large travel range

Scanning and quick return



Conclusions

- **Single-moving part with simple structure and 6-DOF motion capabilities**
- **Actuator design based on novel dual-force actuation scheme**
- **Specifications:**
  - Positioning resolution: 3 nm rms
  - Travel range: 5 mm translation in *x* & *y*
  - Light moving part: 0.267 kg
- **Applications:**
  - Nano-manipulation
  - Lithography
  - Scanning
  - Nanoscale vibration isolation
  - Nano-indentation

Conclusions

Acknowledgements

This research work was supported by the National Science Foundation under Grant No. CMS-0116642 through Dr. Won-jong Kim.

Thank you

Questions