Marcel Thomas *Prof. Jung-Hoon Chun* *Prof. Martin Culpepper*

Characterization of taper effects in TFGs

MIT's Laboratory for Mfg. & Productivity

An interdepartmental laboratory within SoE

Manufacturing-centric research

Laboratory for Manufacturing and Productivity

Founded more than 30 years ago

PROCESSES AND EQUIPMENT

GREEN

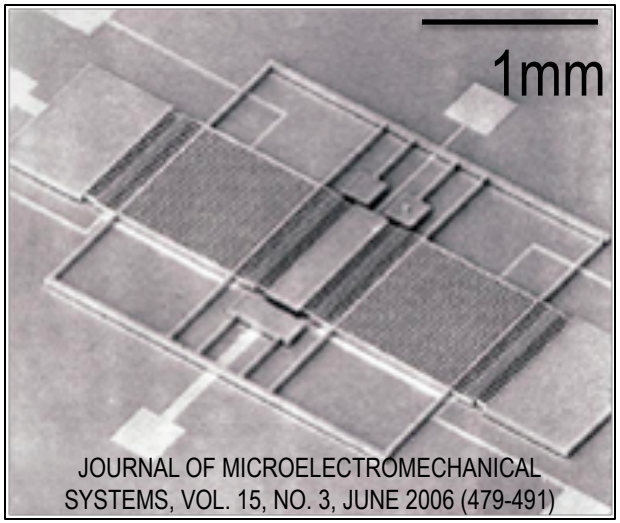
Over $7M research volume per year

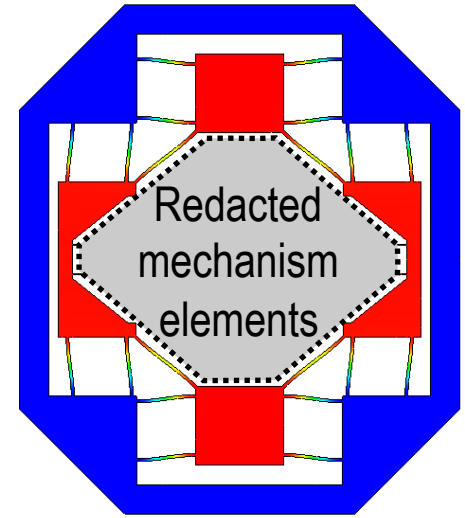
SYSTEMS

2012-2013 Research

Purpose:

Sensitivity analysis for meso-scale solid-state gyroscope





Due to sponsor and IP restrictions, only a portion of the mechanism may be shown

Import:

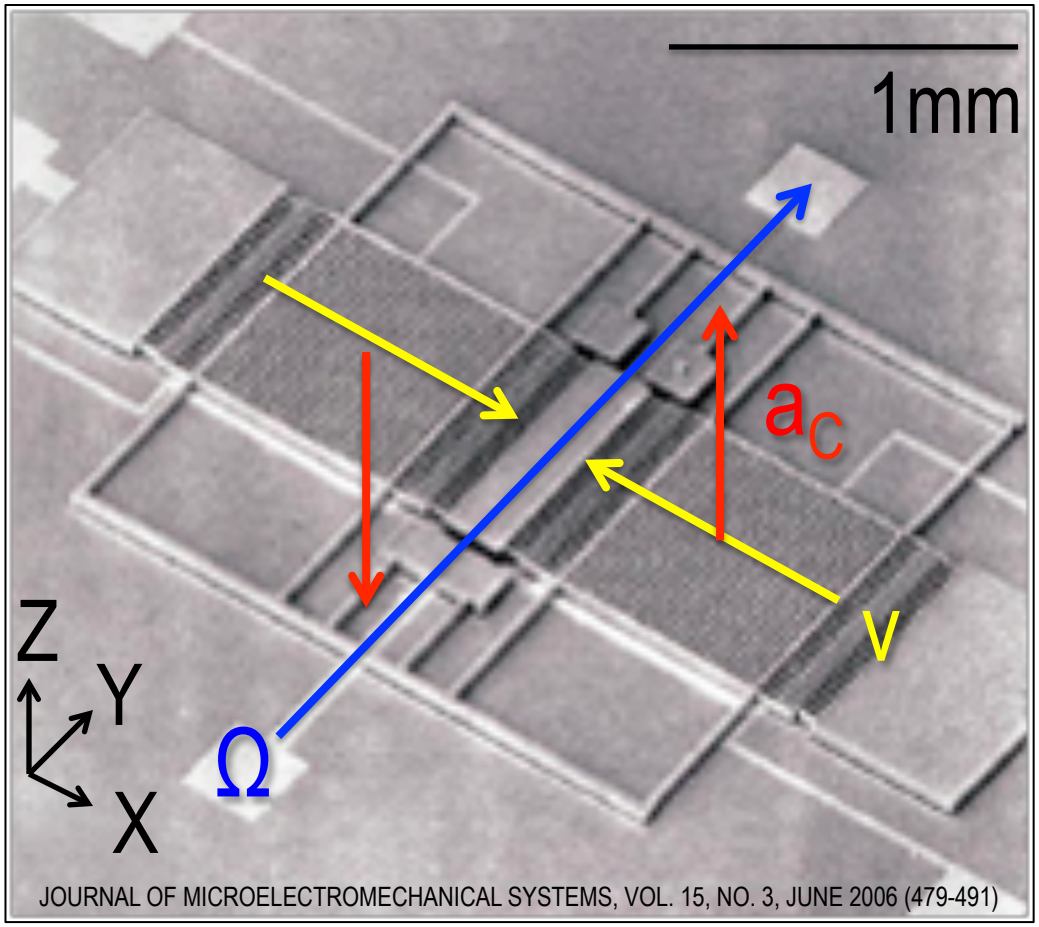
High performance solid-state gyroscope for inertial guidance and positioning

Impact:

Impact only if sensitivity to geometric errors is acceptable

Obtaining physical prototype requires 5 axis machine

Tuning Fork Gyroscope



$$\vec{a}_C = 2\vec{\Omega} \times \vec{v}$$

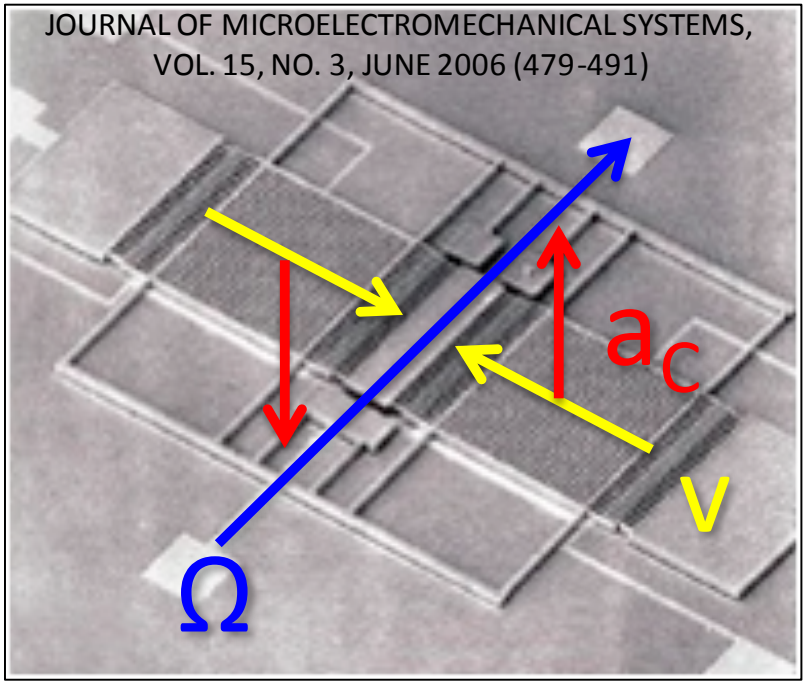
Fundamental problem

Mass and stiffness of components need to be closely matched

Sub-micron taper and thickness variations in beams ruin performance

Masses with opposing motions (yellow and red arrows) required

$$\vec{a}_C = 2\vec{\Omega} \times \vec{v}$$

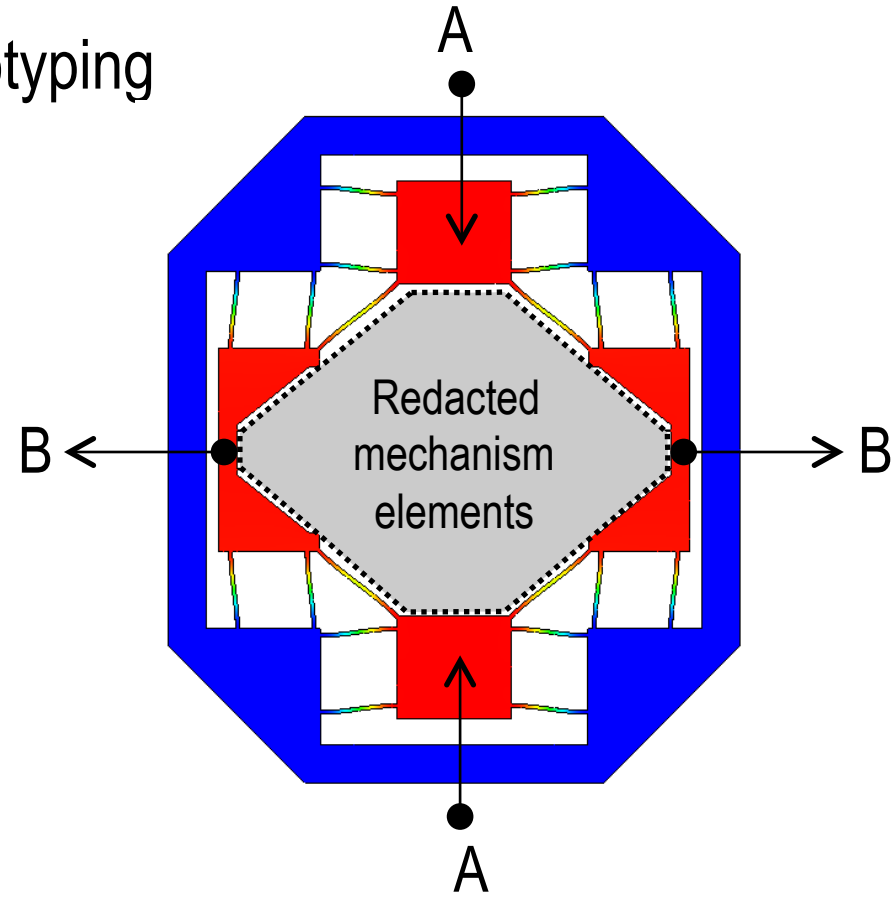


Solution

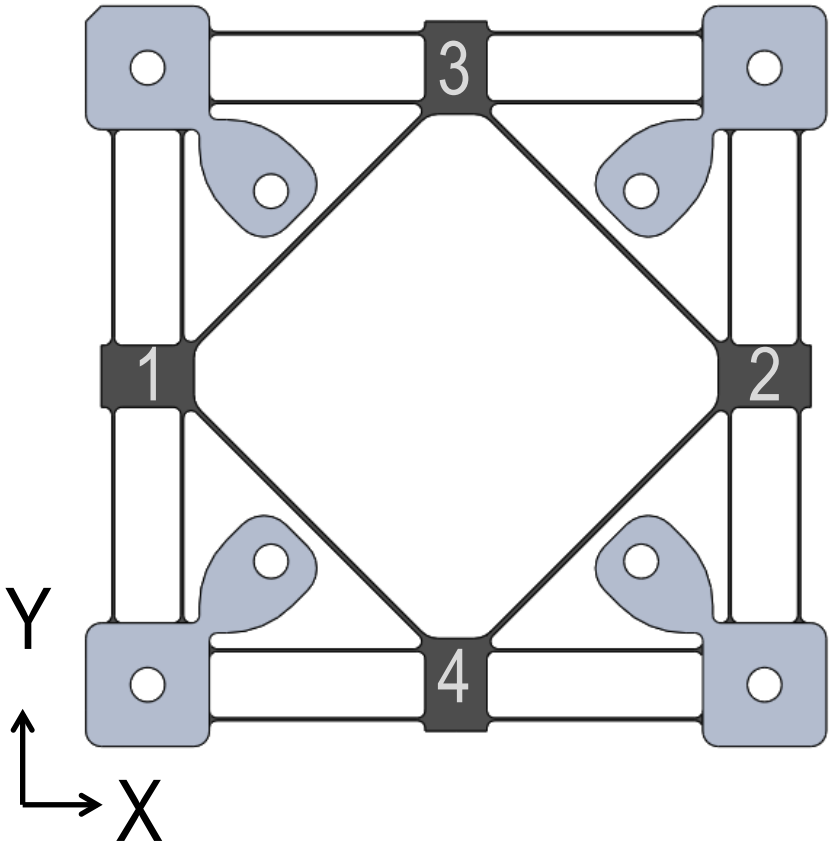
New design is inherently better at providing correct motions than prior art

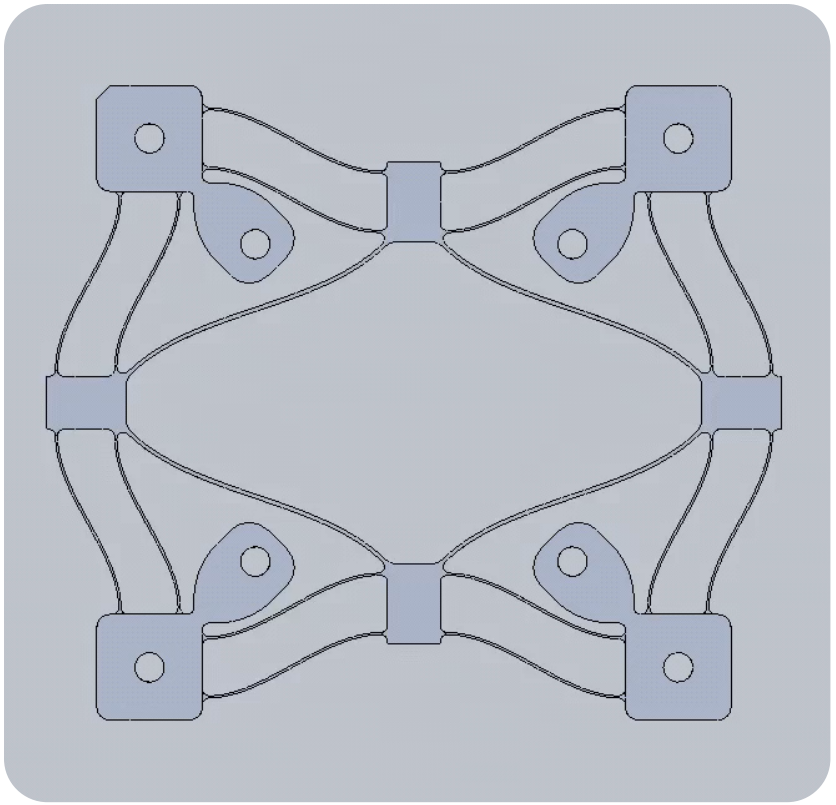
Need to determine sensitivity to taper/thickness variations in beams

5 axis need for prototyping



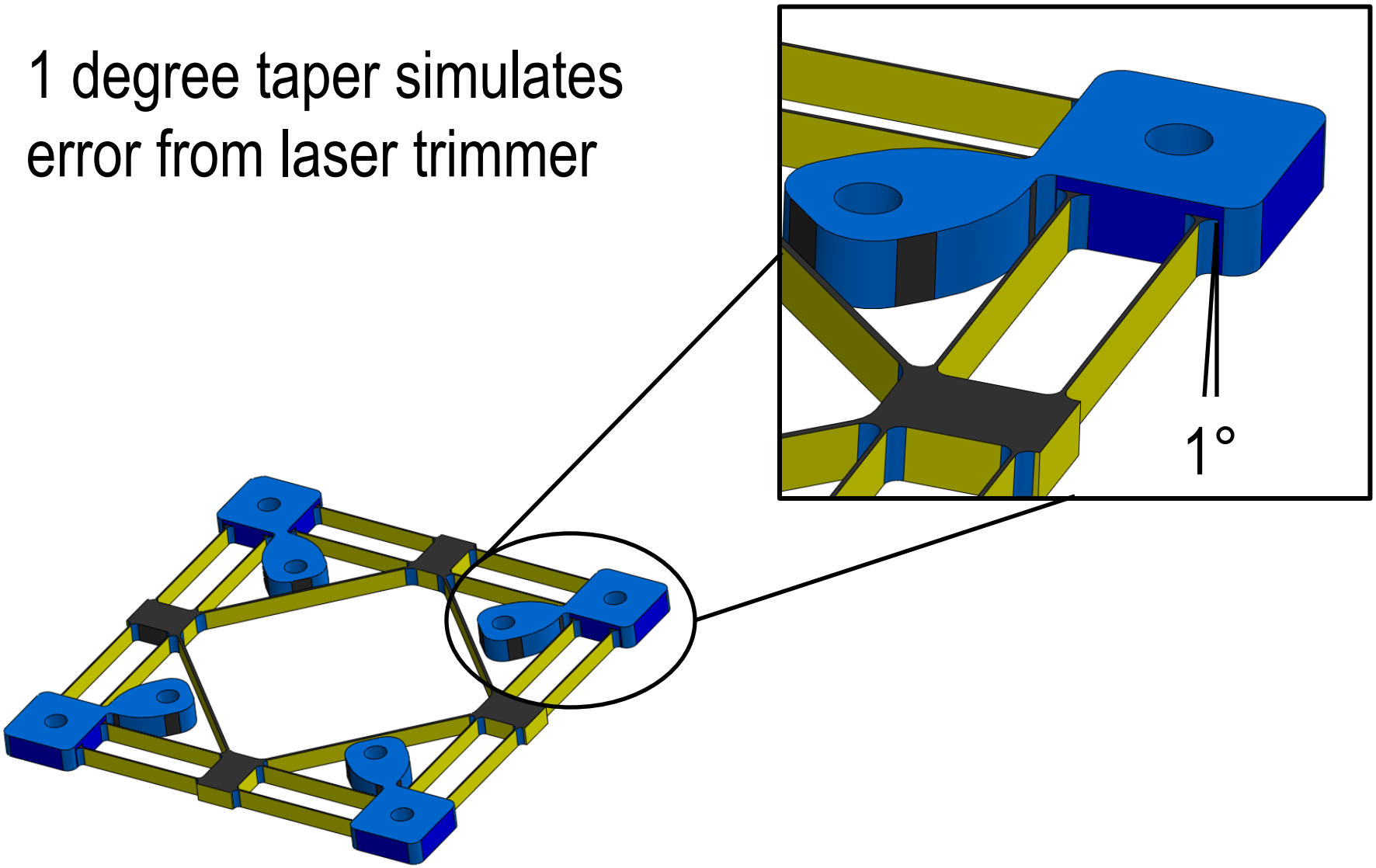
Drive Axis Flexure Concept





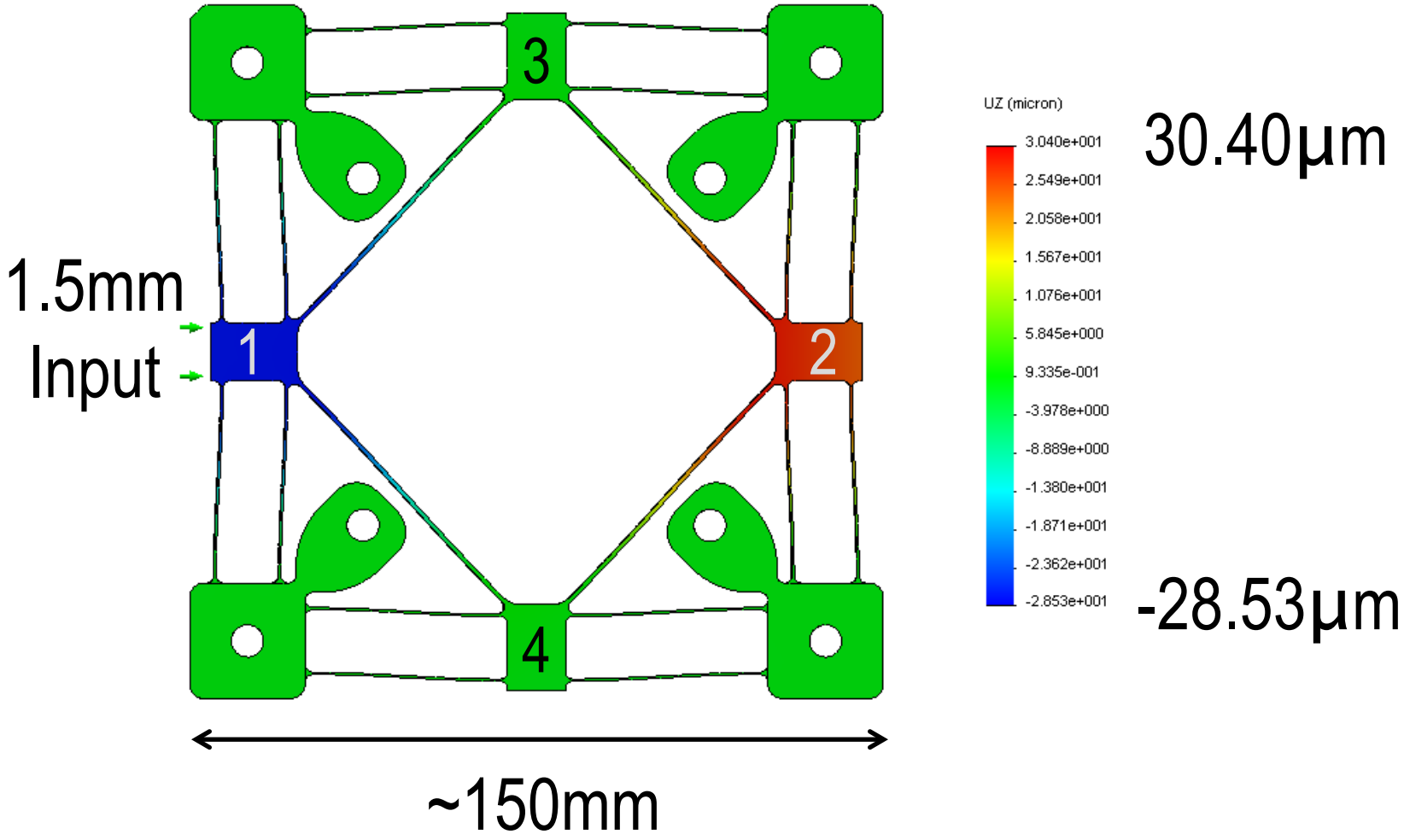
Introduce Taper

1 degree taper simulates error from laser trimmer

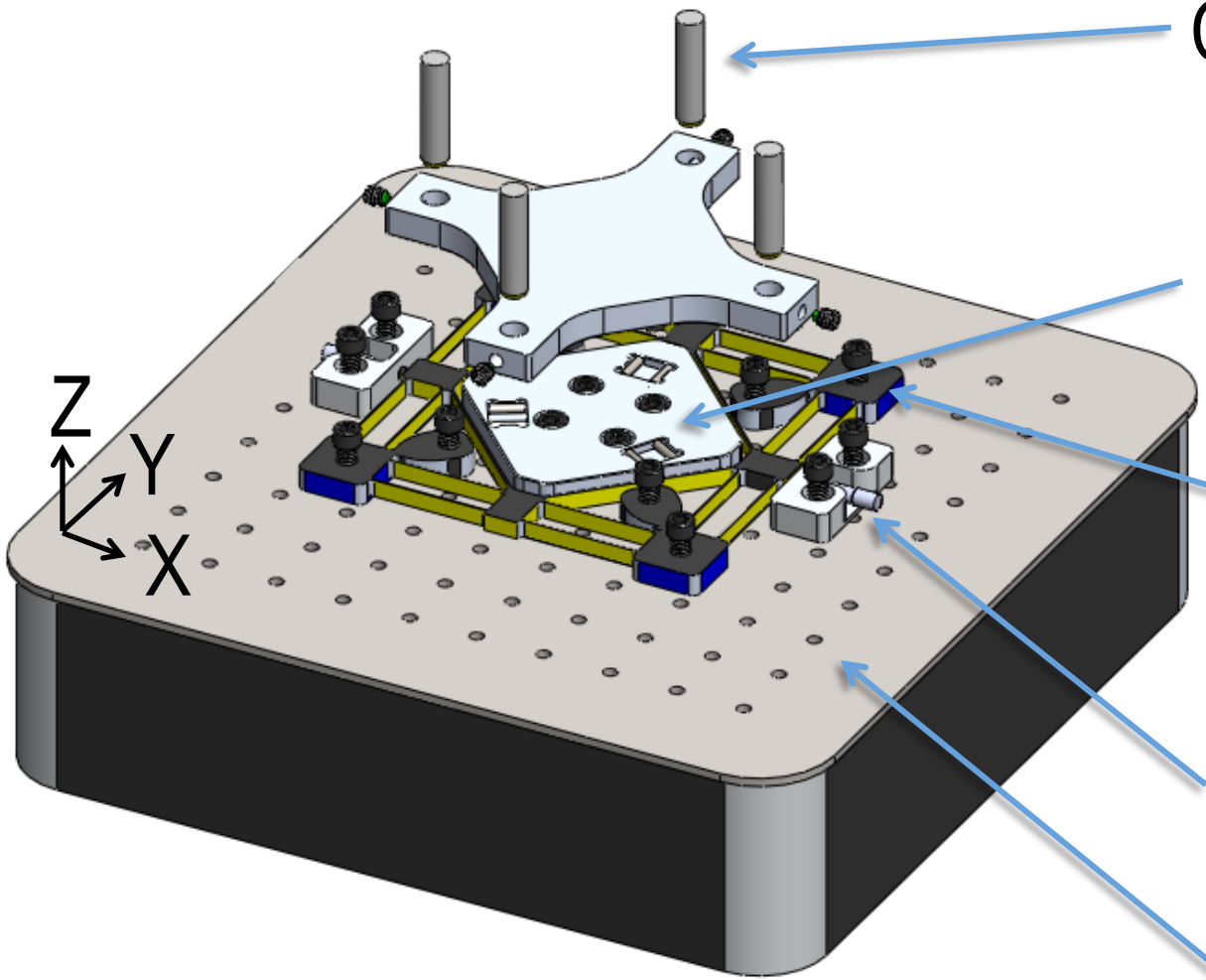


FEA simulation of defects

1° of taper → ~2% out-of-plane motion



Experimental Design Detail



Capacitance Probes

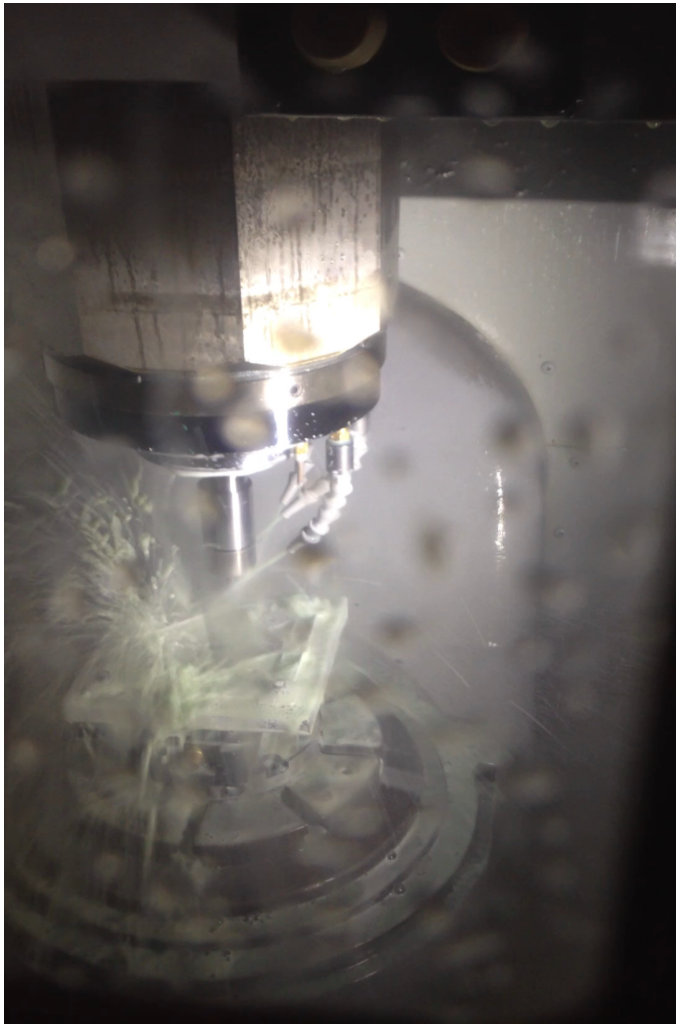
Kinematic Coupling

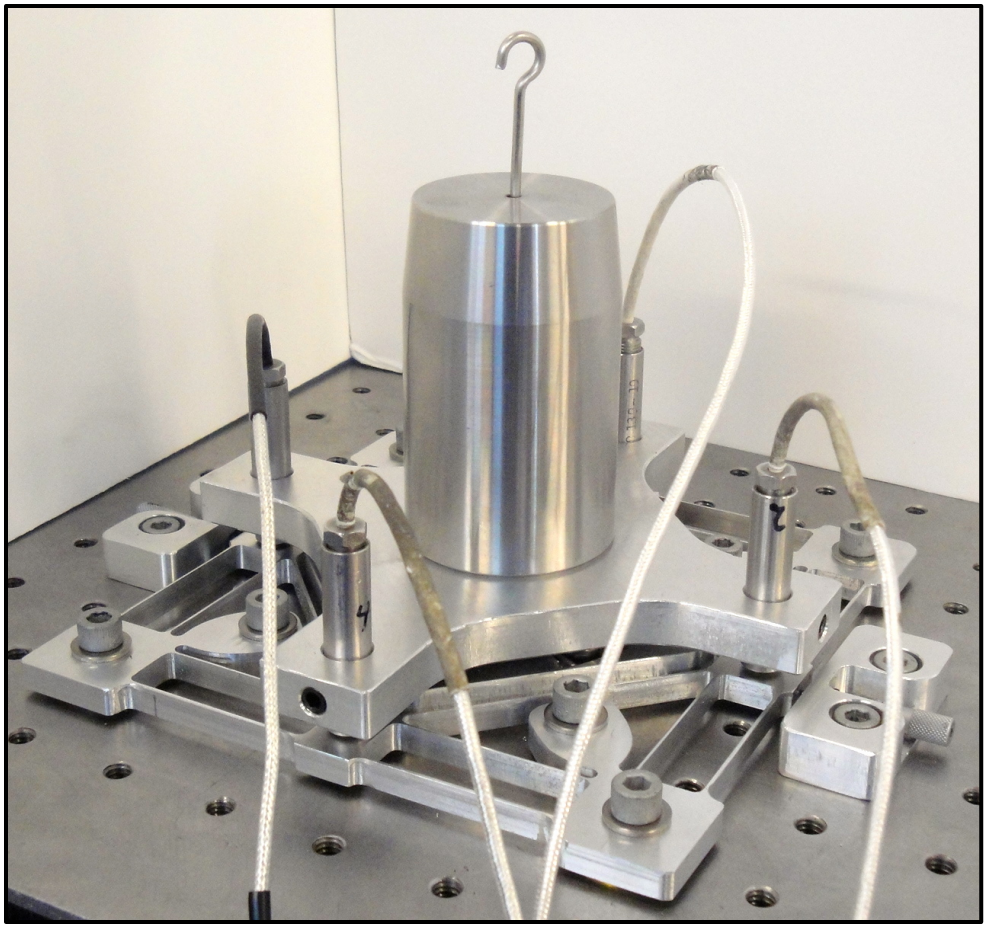
Flexure

Micrometer Heads

Optical Table

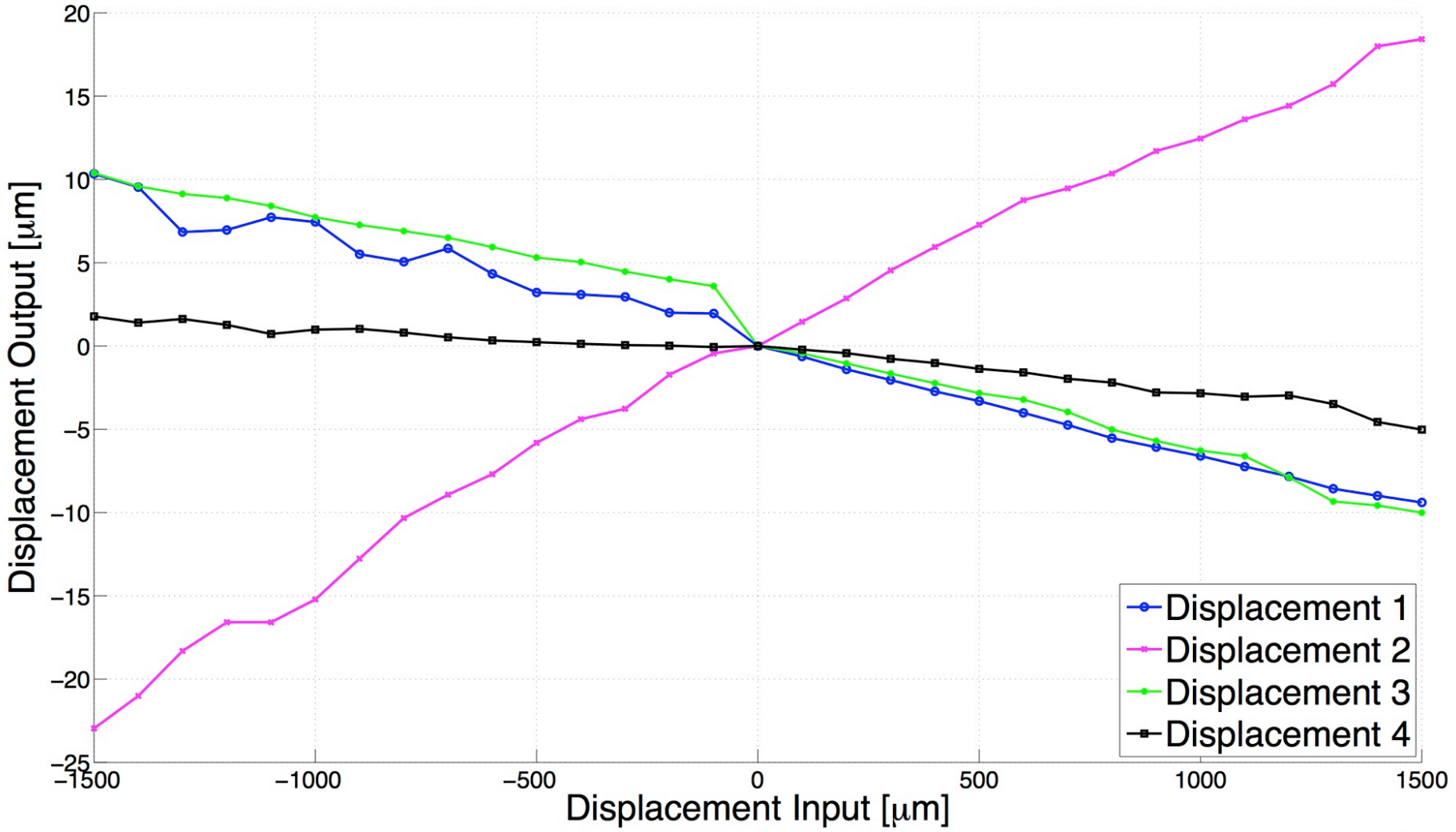
Prototype and Experimental Setup





Mori Seiki NMV1500DCG

Measured Displacements

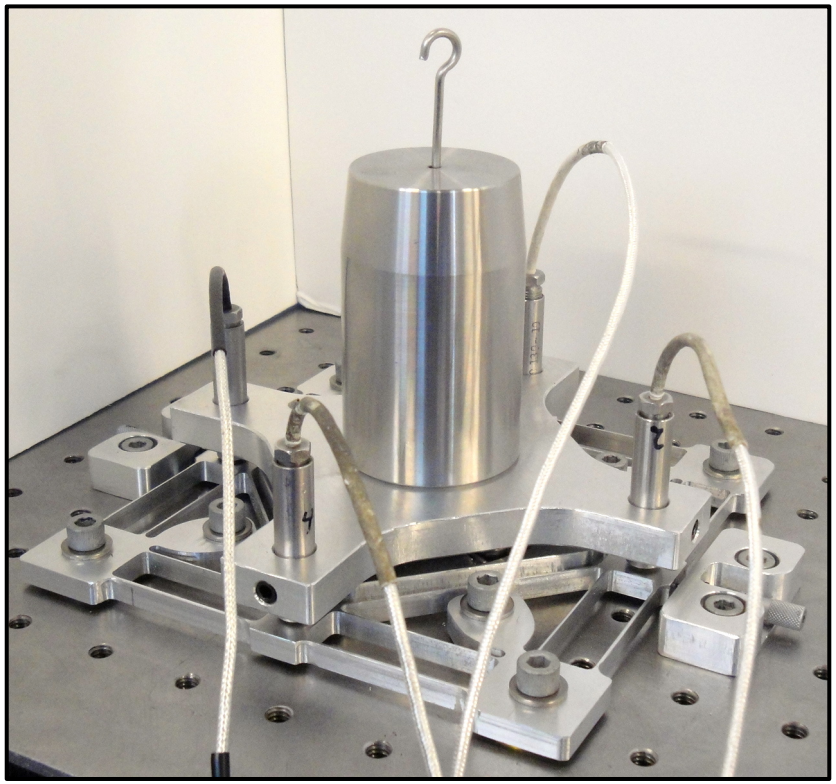


Summary

~4x reduction of out-of-plane motion from state-of-the-art

Applied precision machine design principles
- Kinematic Coupling
- Flexure

Hands-on learning with 5-axis mill



Education – Design & Manufacturing

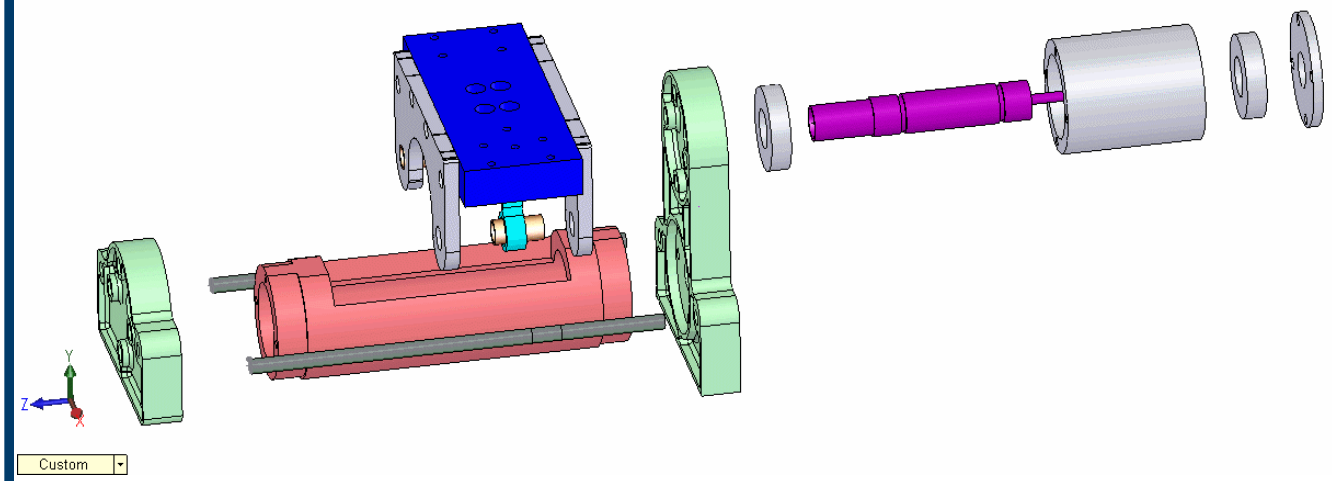
2.72 (MIT student education)
Elements of Mechanical Design

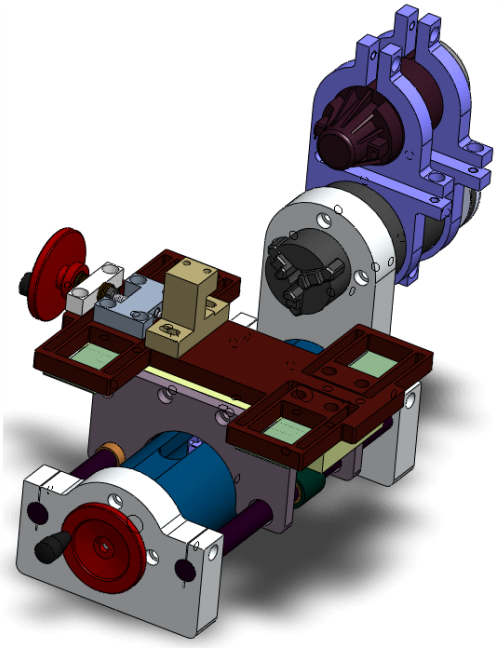
- HTM modeling
- Design example
- Stiffness
- Accuracy
- Repeatability

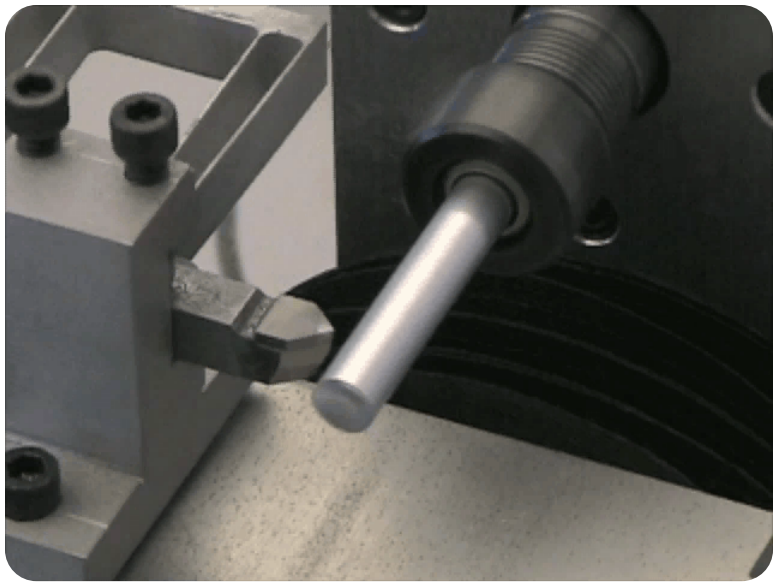
2.75s (Professional education)
Advanced Design & Mfg

- HTM modeling
- Design example
- Stiffness
- Accuracy
- Repeatability

2.72 Precision Lathe Design/Mfg.



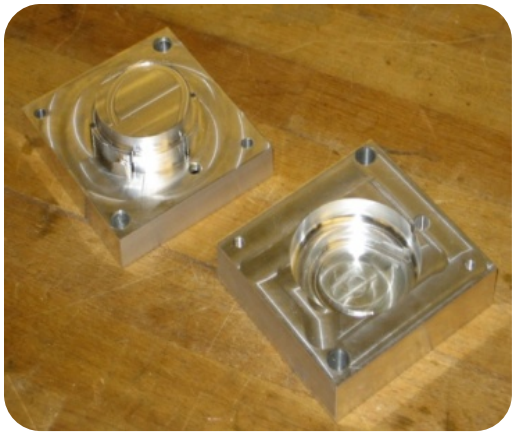




Education – Design & Manufacturing

2.008

Design and Manufacturing II



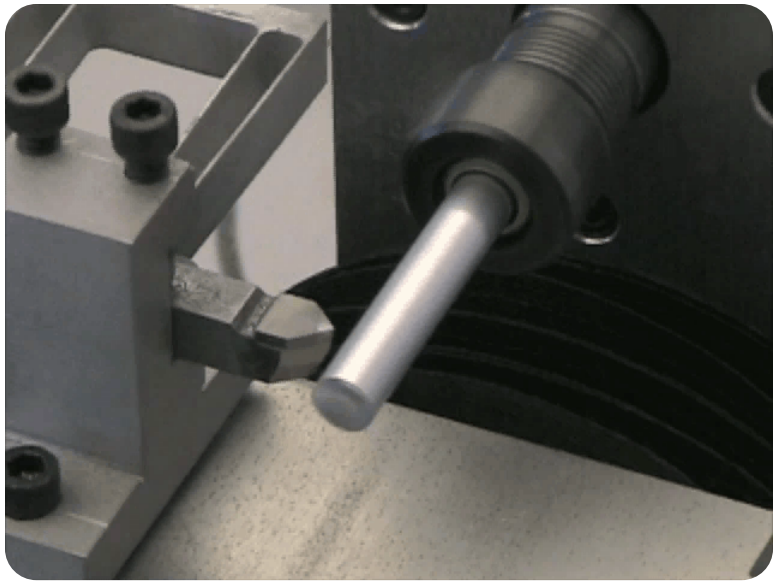
- Emphasis on
  - *Physics*
  - *Stochastic nature of mfg.*
  - *Quality*
  - *Rate*
  - *Cost*
  - *Flexibility*

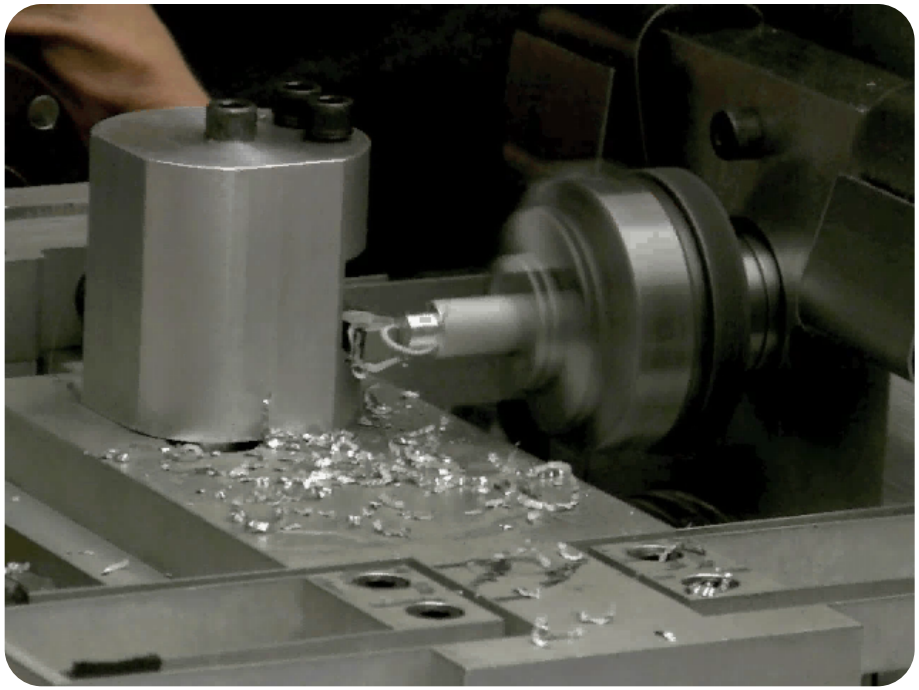
Questions and Acknowledgements

Many thanks to our sponsors

MTTRF

MORI SEIKI
THE MACHINE TOOL COMPANY



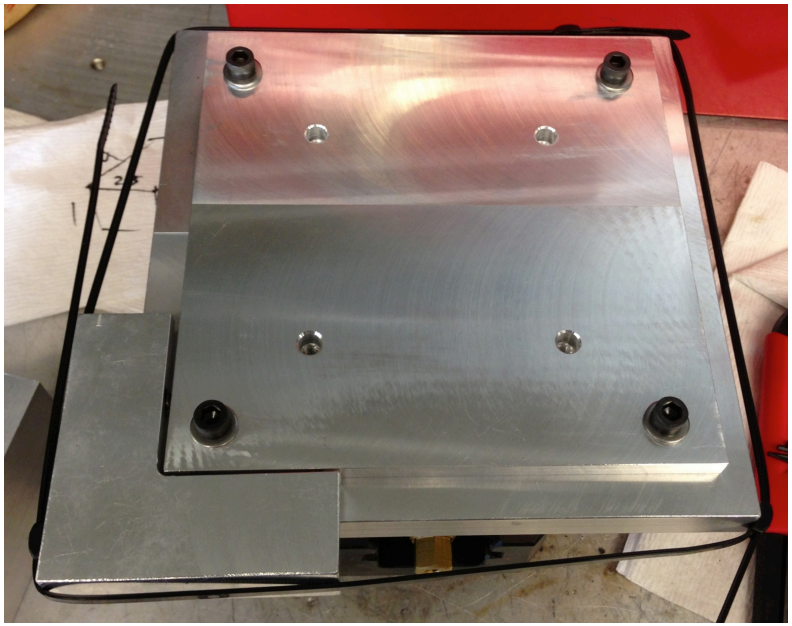


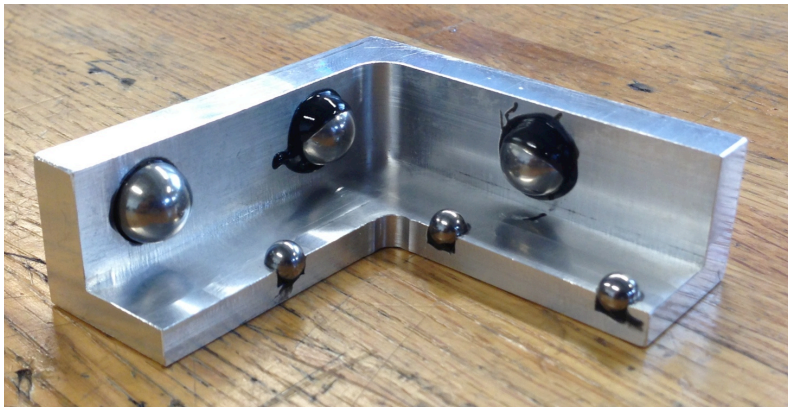
DRAPER LABORATORY

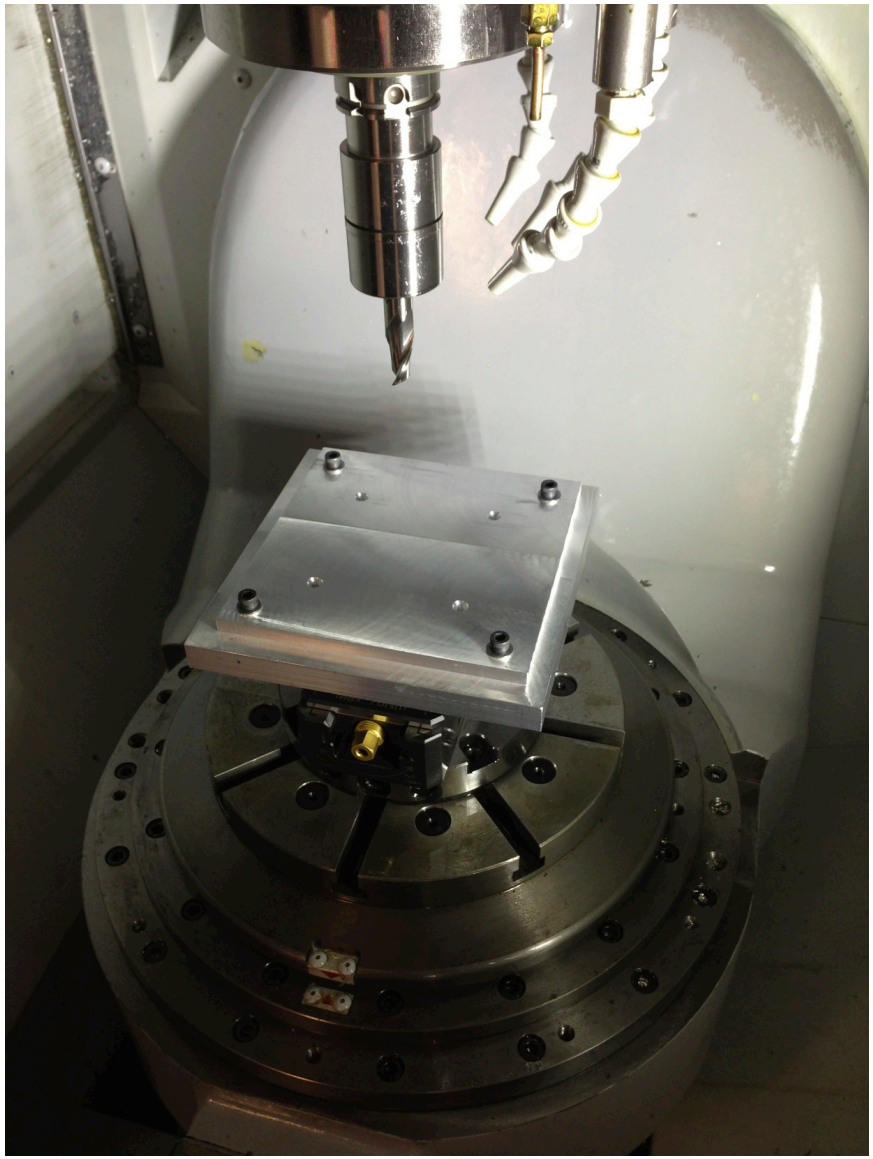
MITMECHE

Backup Slides

Manufacturing







Experimental Setup