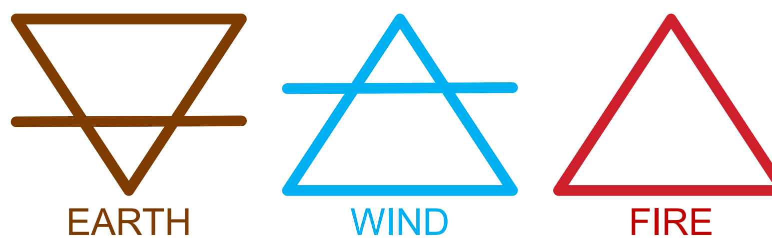
EARTH, WIND, & FIRE: THE NEW FAST-SCANNING VELOCIPROBE

CURT PREISSNER

Principal Mechanical Engineer
Advanced Photon Source



TUAA02-Tuesday, September 13th

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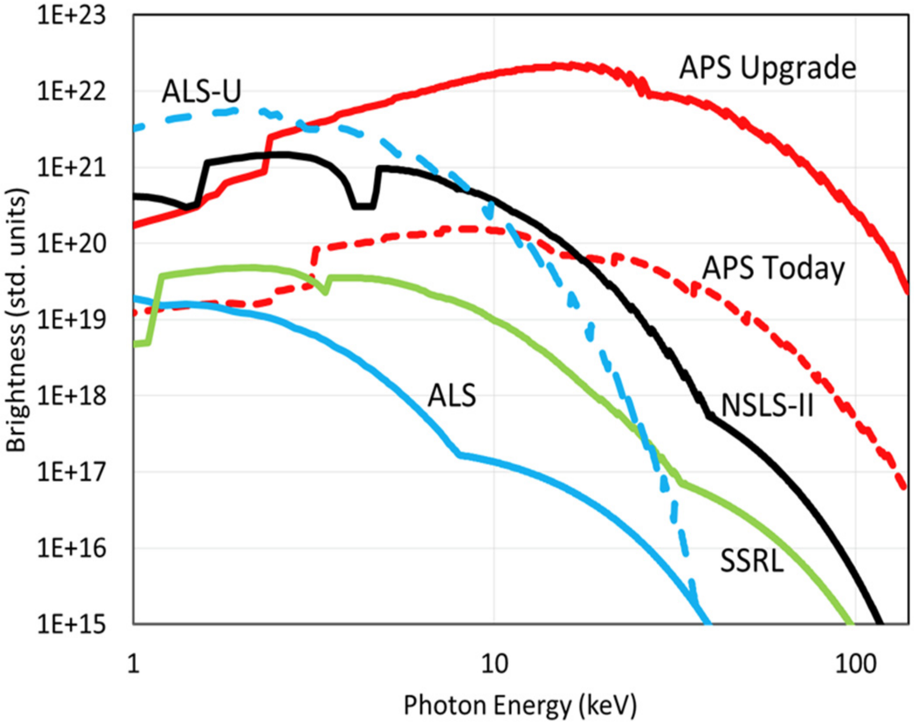
APS-U

An opportunity to revolutionize scanning probe microscopies…



- 100X+ increase in brightness
- Micro/nanoprobes are brightness driven
- Possible to get 100% of APS flux into a 300 X 250 nm spot!!!
- Can use increase in flux to:
  - Reduce scanning time
  - Increase resolution
  - Some combination

VELOCIPROBE OVERVIEW

Instrument goals and concept

- Goals
  - Build prototype high-speed, high-resolution X-ray nanoprobe
  - Scan a 1μm X 1μm area in 10 seconds or less at 10 nm spatial resolution
  - Extended objects and high spatial resolution through ptychography
  - Fluorescence mapping at better than 50 nm
  - Tomography

- Concept
  - Design vibrationally and thermally stable instrument
  - Employ control strategy to reject disturbances and maximize bandwidth
  - Explore nontraditional scanning and image acquisition modes

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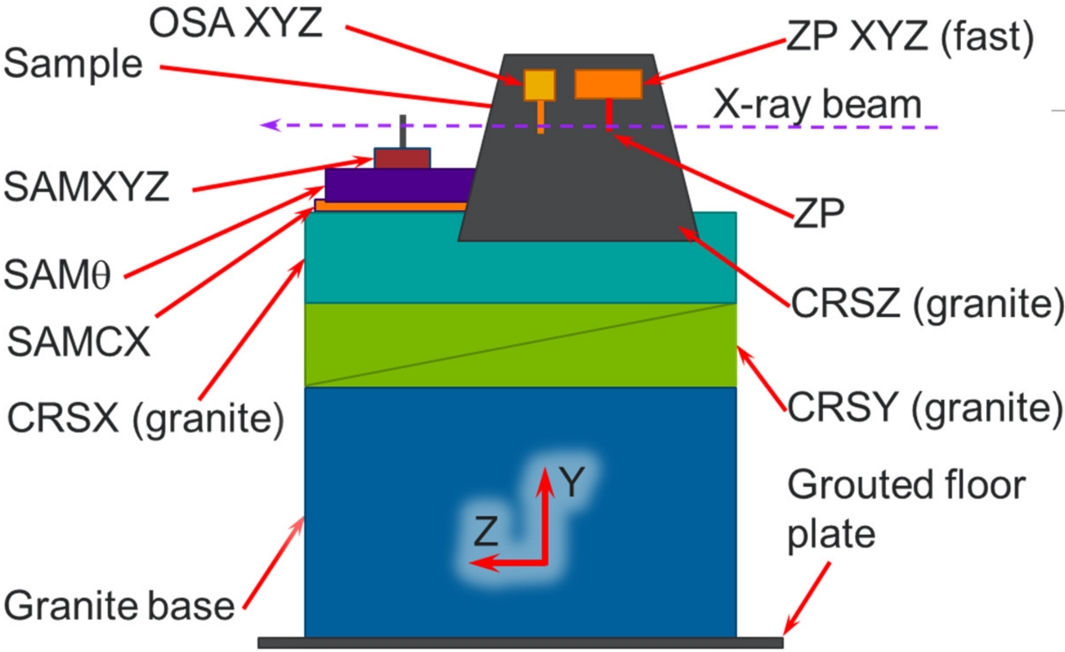
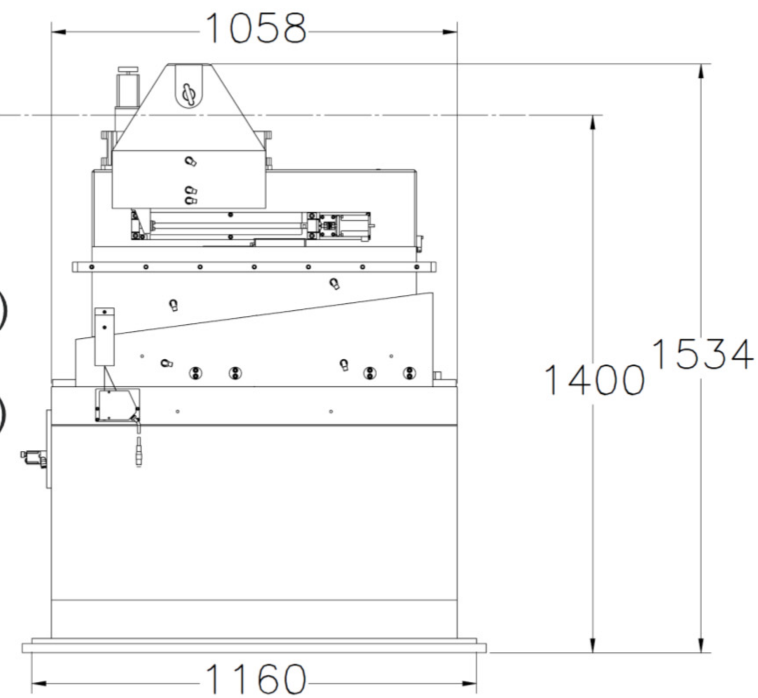
ptychography + fluorescence + APS-U flux = need for speed

VELOCIPROBE MECHANICS

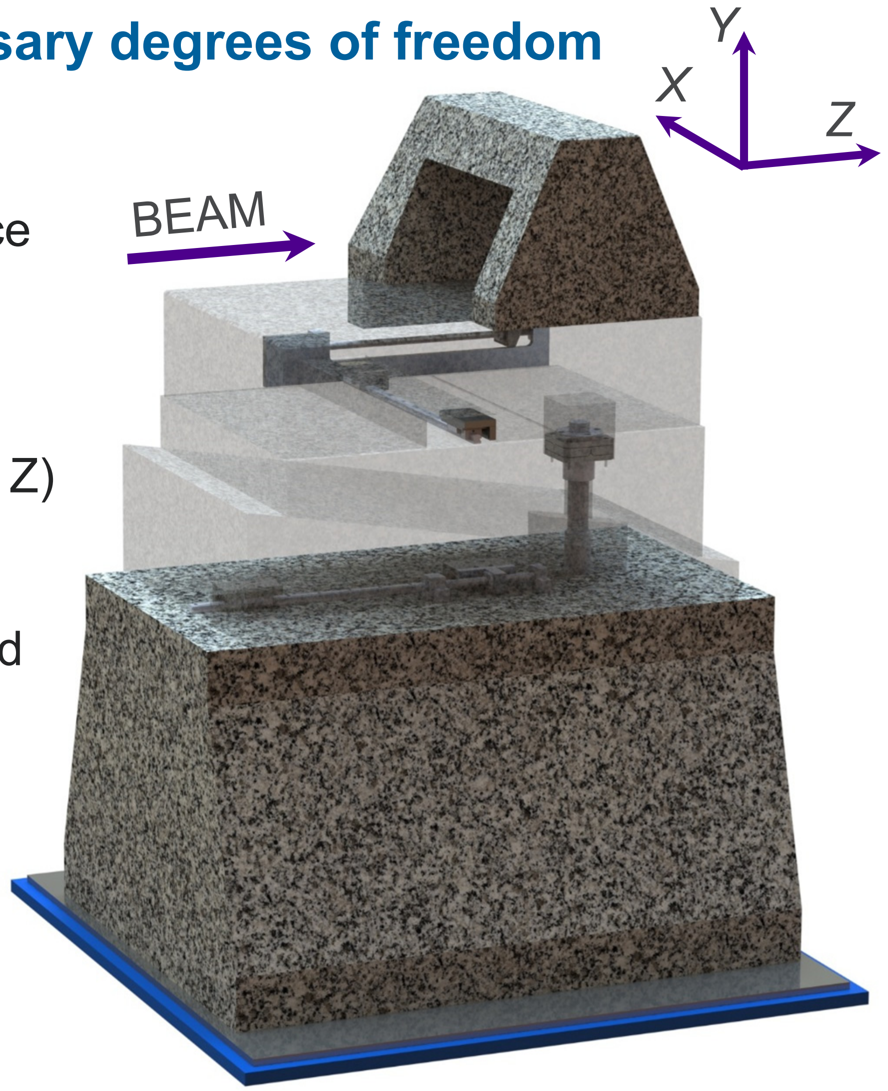




COARSE MOTION CONCEPT

Maximum stability, minimum necessary degrees of freedom

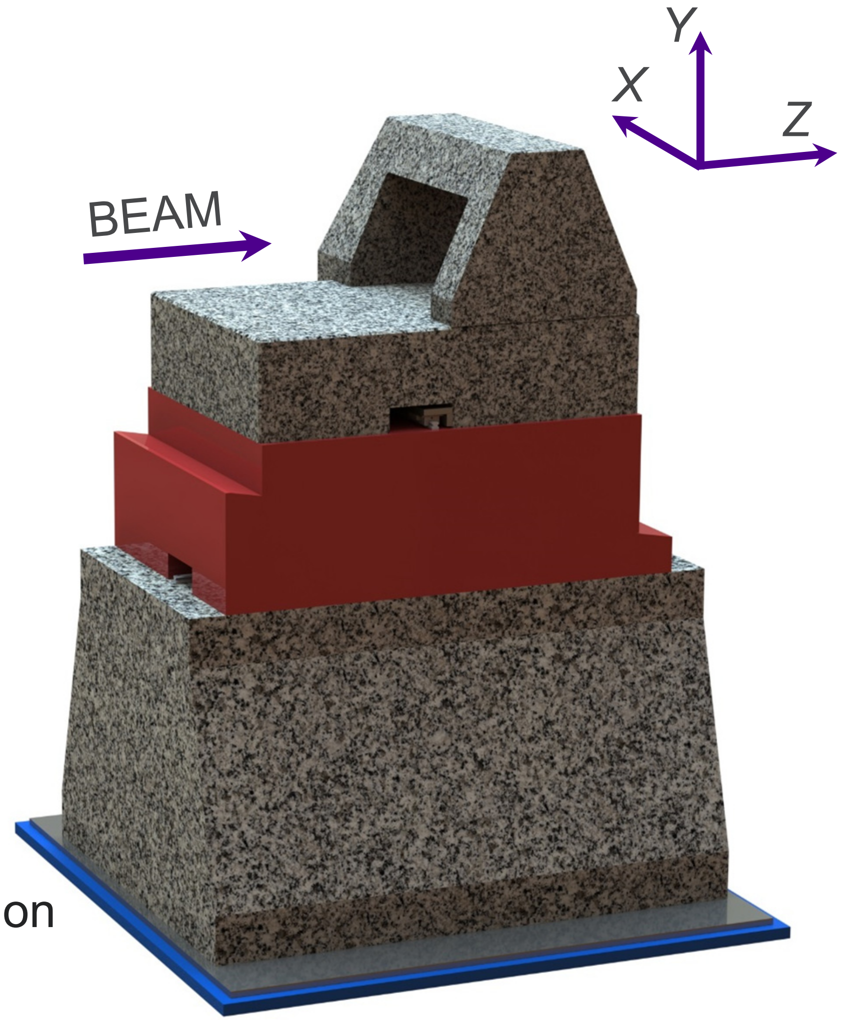
- Coarse axes used only for alignment
- Why compromise stability with compliance from rolling-element bearings?
- Novel concept:
  - Granite stages
  - Travel 25 mm, 10 mm, 400 mm (X, Y, Z)
  - Integrated air bearings guide all axes
  - *Fly-move-land* operation
  - As stable as solid granite when landed
- Designed to be inherently stable
- Mass: ≈3612 kg (7946 lb)
- Air bearing lift: ≈<5 μm
- Vendor: Starrett Tru-Stone
- US patent in progress: 15/253,092



Y AXIS STAGE (VERTICAL)

Air-lifted, stepper driven wedge-style

- Motor
  - Oriental motor PKP268MD14BA-L
  - .9 deg./step, bipolar, 4-lead, 2.23 N*m
- Drive
  - THK MDK 1402-3 Ball Screw
  - 2 mm pitch, 145 mm travel
- Guiding
  - THK HSR 15A Linear Guide
  - THK SLF 40 Ball Spline
- Theoretical minimum full step
  - 5 μm for driving wedge (horizontal)
  - .7 μm for driven wedge (vertical)
- Encoder: Keyence LK-G80, <.1 μm resolution
- Moving mass ≈850 kg
- Friction-stable 7.5 degree wedge



Y AXIS STAGE

Principle of operation

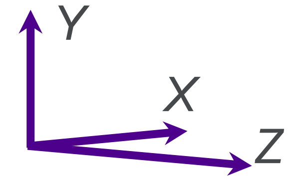
Driven wedge

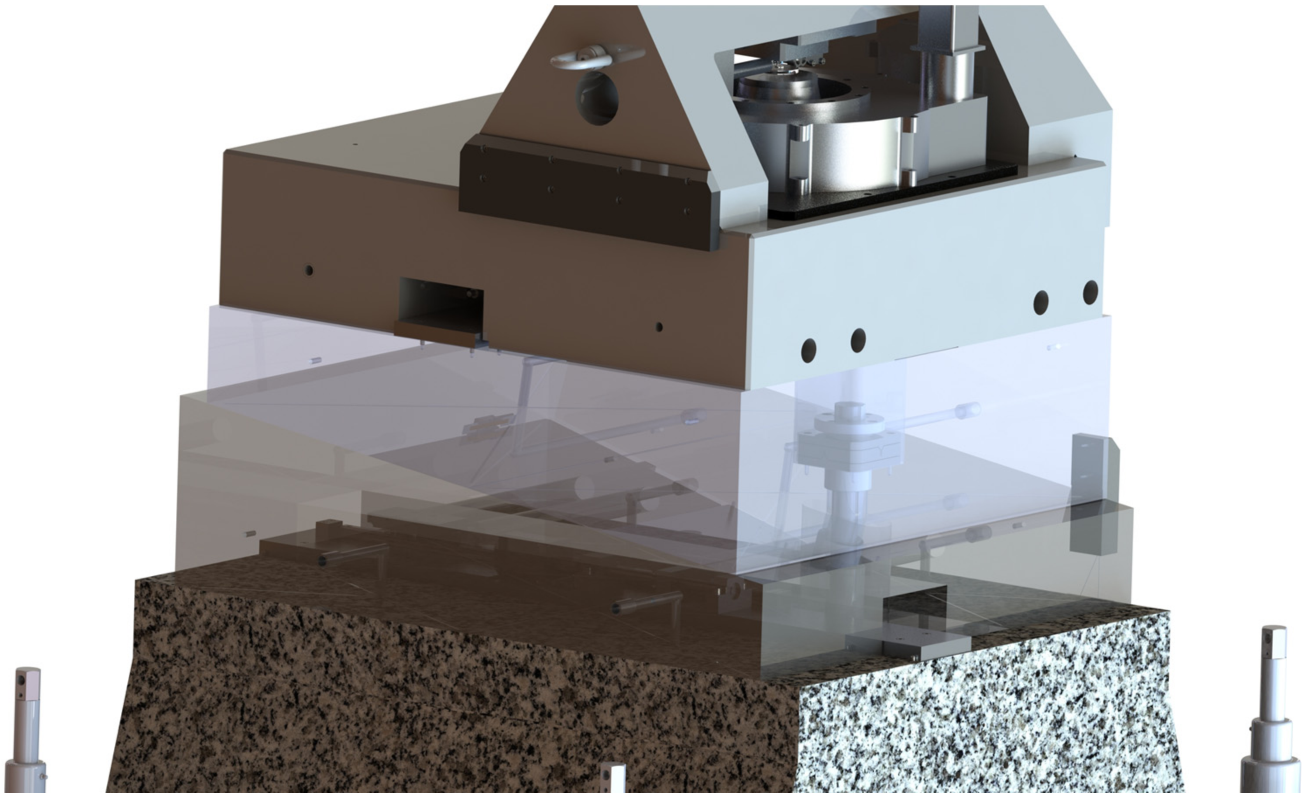
Driving wedge

Proper constraints are applied to ensure correct motion

Y AXIS STAGE

Kinematics of wedges

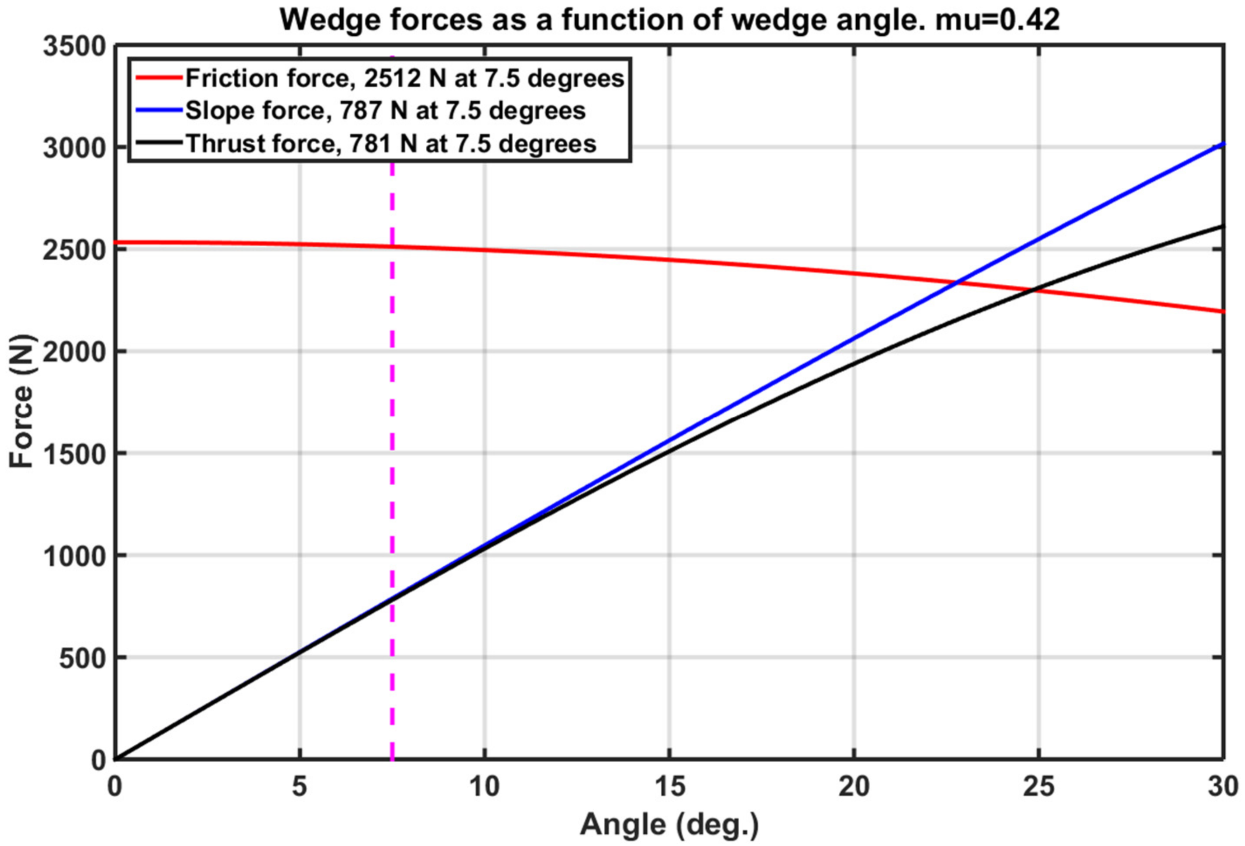




- One axis of motion needed on each wedge ⇒ five constraints are needed
- Driving wedge has THK rail, driven wedge has THK ball spline
- Flexures allow for movement when the air bearing is lifted

Y AXIS STAGE

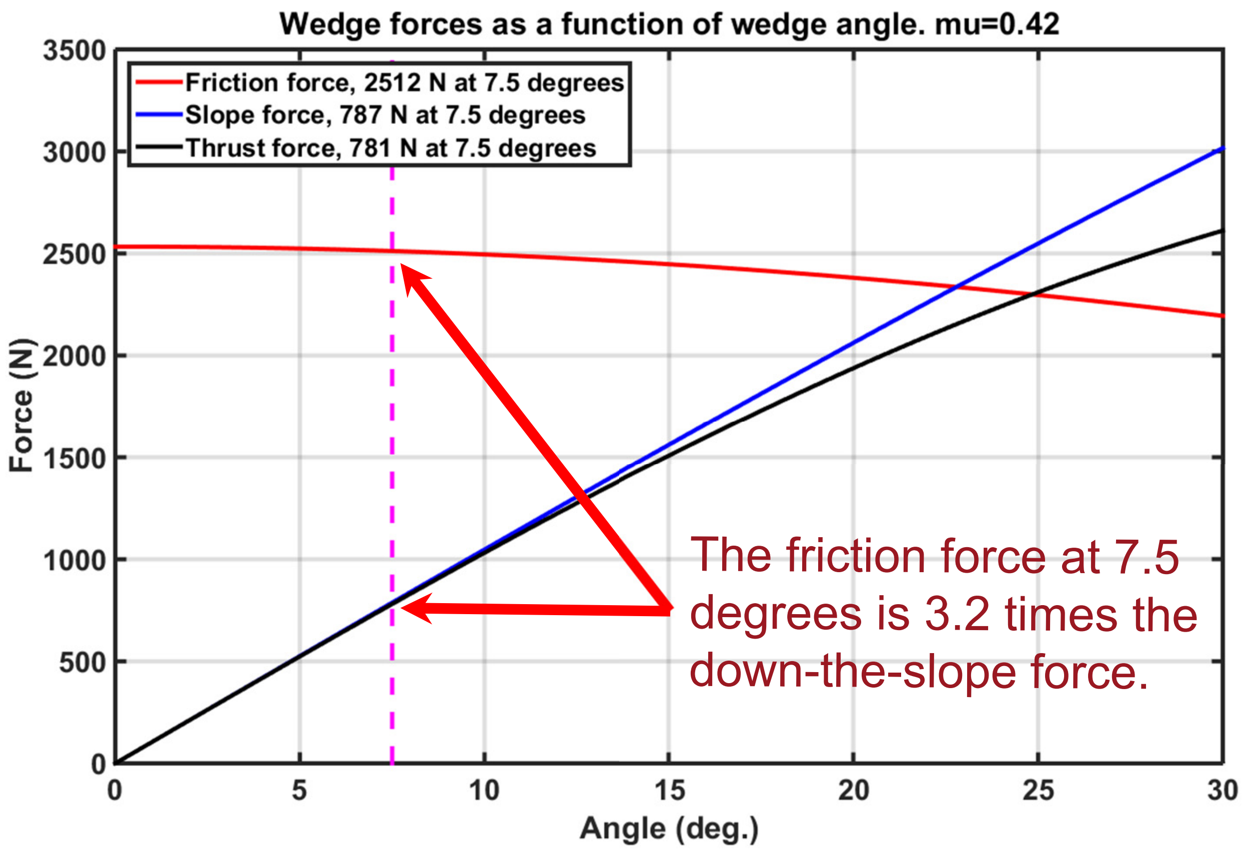
Wedge forces



- Friction has been measured for the particular granite and surface finish

Y AXIS STAGE

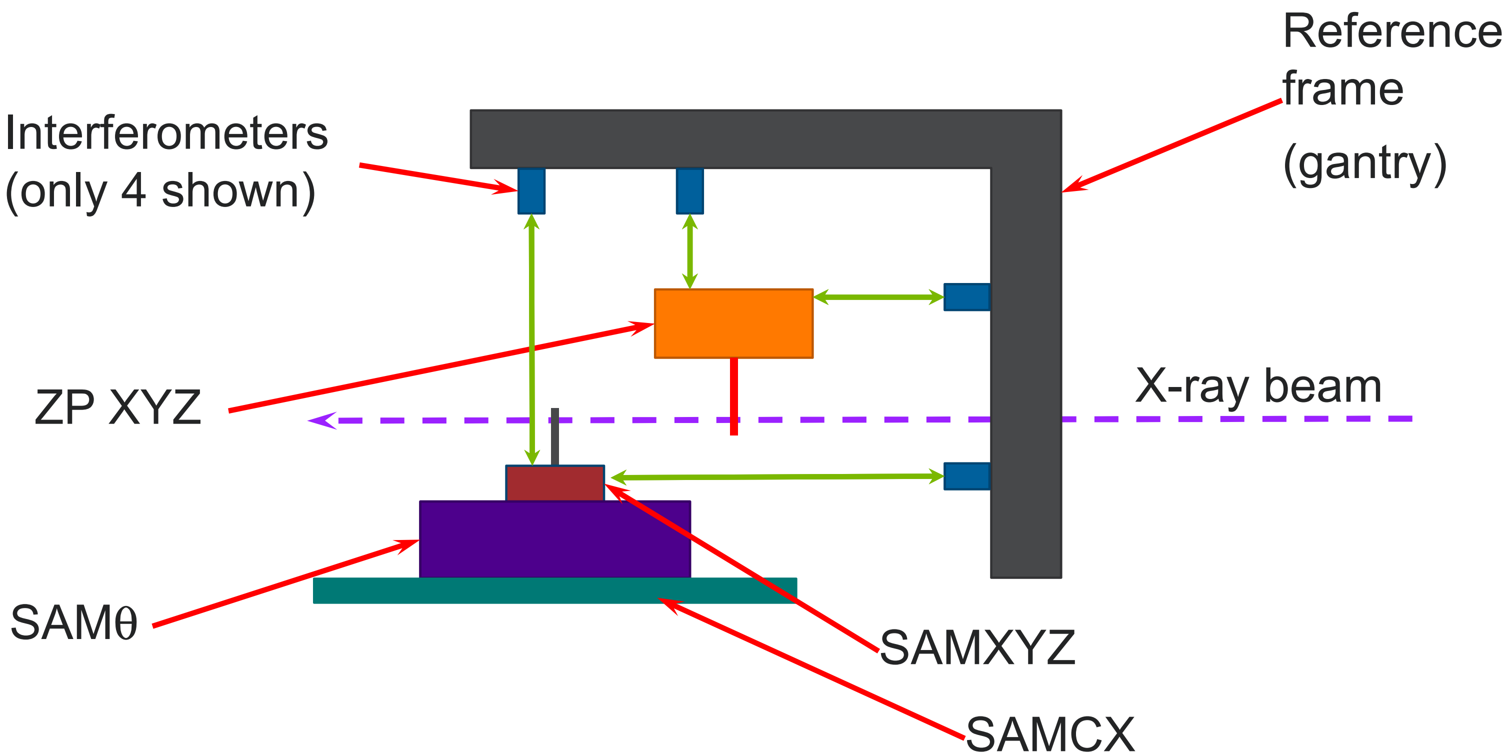
Wedge forces



- Friction has been measured for the particular granite and surface finish
- Stage is rigid when air lift is vented

METROLOGY USING INTERFEROMETERS

Single reference frame with 6 interferometers (only Y and Z axes shown)



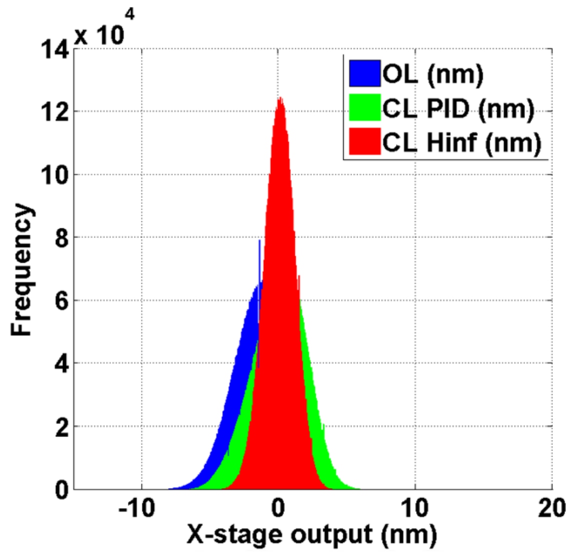
- Using Attocube IDS sensors
- Need to accommodate the rotation of sample (cylindrical/faceted reference surface)

INSTRUMENT CONTROL

Optimized negative feedback approach

- H_∞ Mixed-Sensitivity Minimization:
  - Increase tracking bandwidth
  - Increase position resolution
  - Better disturbance rejection
  - Adequate noise rejection
  - Robustness to unmodeled system dynamics
  - Can exploit axes coupling
- Techniques proven in SPM field and for X-ray microscope
- Implemented on fast FPGA hardware
  - NI-9039 cRIO hardware
  - Can implement almost any algorithm

Comparison using an existing instrument

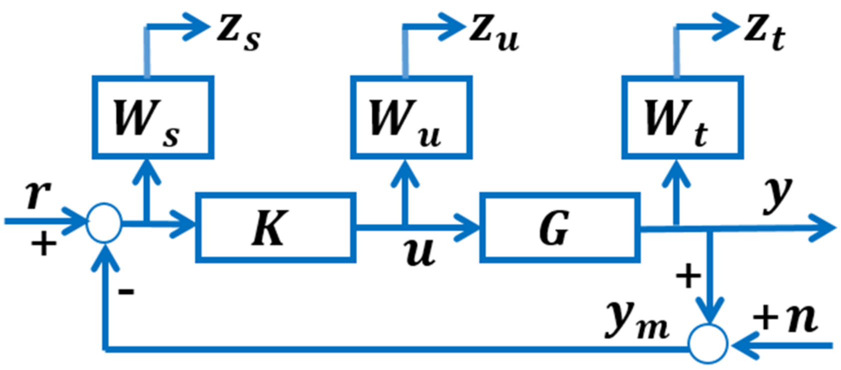


- Resolution:
  - Hinf 3.33 nm vs PID 6.08 nm
  - 45% better than PID
- 3 dB Bandwidth:
  - Hinf 31.2 Hz vs PID 5.6 Hz
  - >5 times better than PID

Mashrafi ST, Preissner C, Salapaka SM, Zhao H. ASPE 28th Annual Meeting. 2013.
Mashrafi, Salapaka, and Preissner (in preparation)

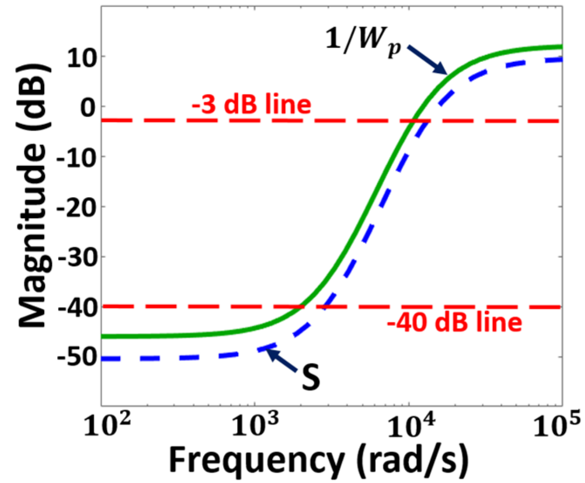
INSTRUMENT CONTROL

Design process

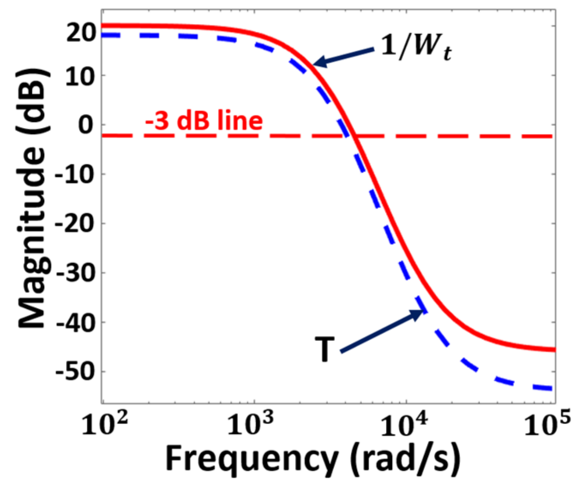


- Exogenous Inputs, $w = [r \quad n]$
- Regulated Outputs, $z = [z_s \quad z_t \quad z_u]$
- $T_{wz} = [W_s S \quad W_t T \quad W_u KS]^T$, t.f. $w \to z$
- Performance objectives are achieved by minimizing the H_∞-norm of the closed-loop transfer function matrix T_{wz} for all stabilizing controllers K.

$$\inf_K \|T_{wz}\|_\infty$$



Weight W_p is chosen such that resulting S has high-pass filter shape

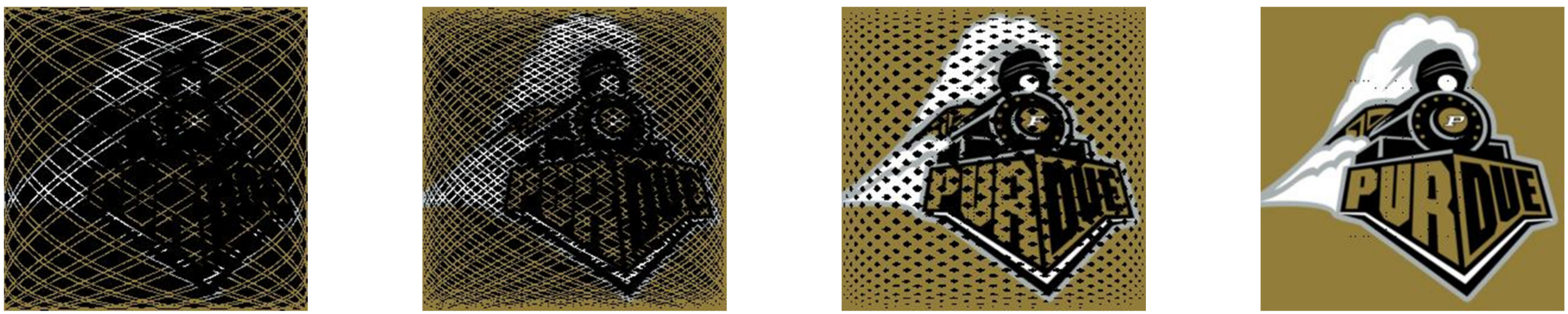


Weight W_T is chosen such that resulting T has low-pass filter shape

INSTRUMENT CONTROL

Better dynamics can translate to more efficient scan trajectories…

Lissajous trajectory scanning



Raster scanning

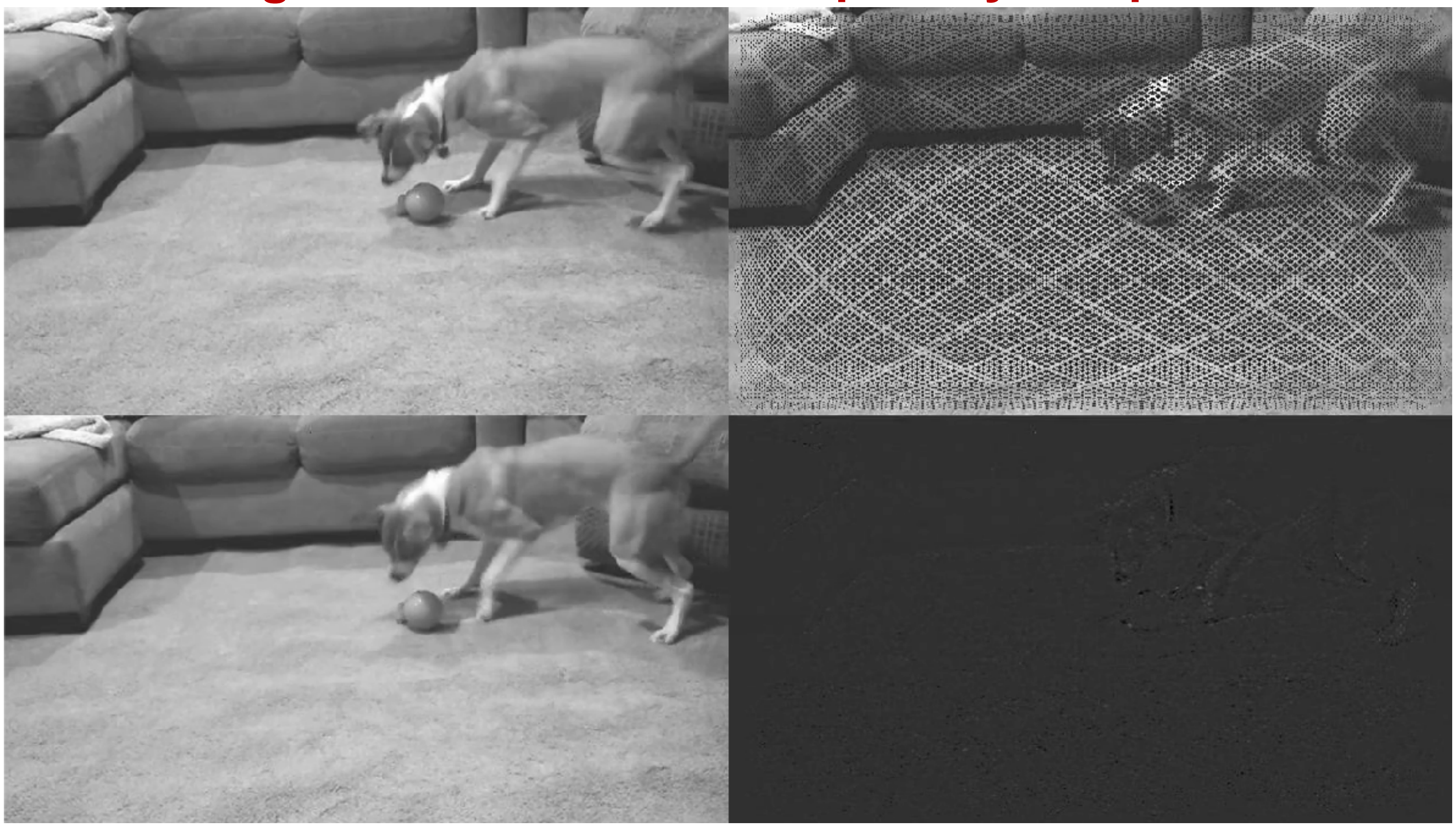
1 ms 2 ms 10 ms 20 ms

Work by Shane Sullivan: Optics Express, Vol. 22, Issue 20, pp. 24224-24234 (2014)

INSTRUMENT CONTROL

More efficient scanning can yield more efficient imaging…

Original movie **Sparsely sampled movie**

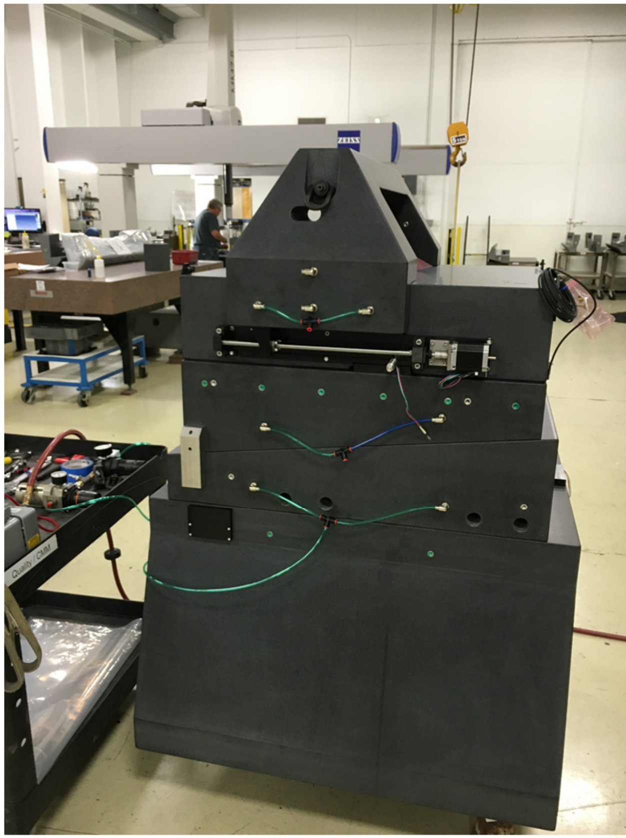


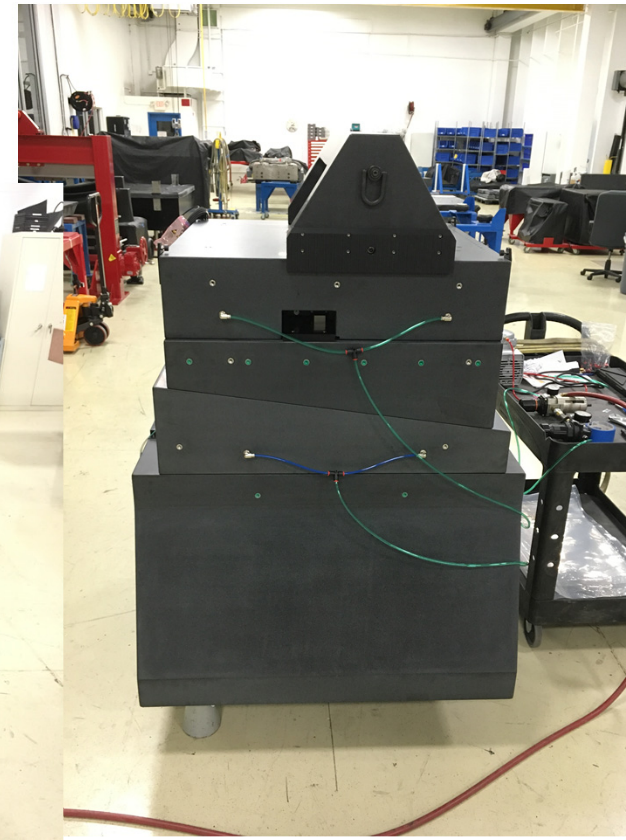
In-painted reconstruction **Error**

Work by Shane Sullivan: Optics Express, Vol. 22, Issue 20, pp. 24224-24234 (2014)

STATUS…

Granite stage assembly will arrive at APS next Tuesday!





MOLTES GRÀCIES!