Mechatronics Approach for the Development of a Nano-Active-Stabilization-System

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Dehaeze Thomas, Bonnefoy Julien and Collette Christophe

[1]European Synchrotron Radiation Facility, Grenoble, France

[2]Precision Mechatronics Laboratory, University of Liege, Belgium

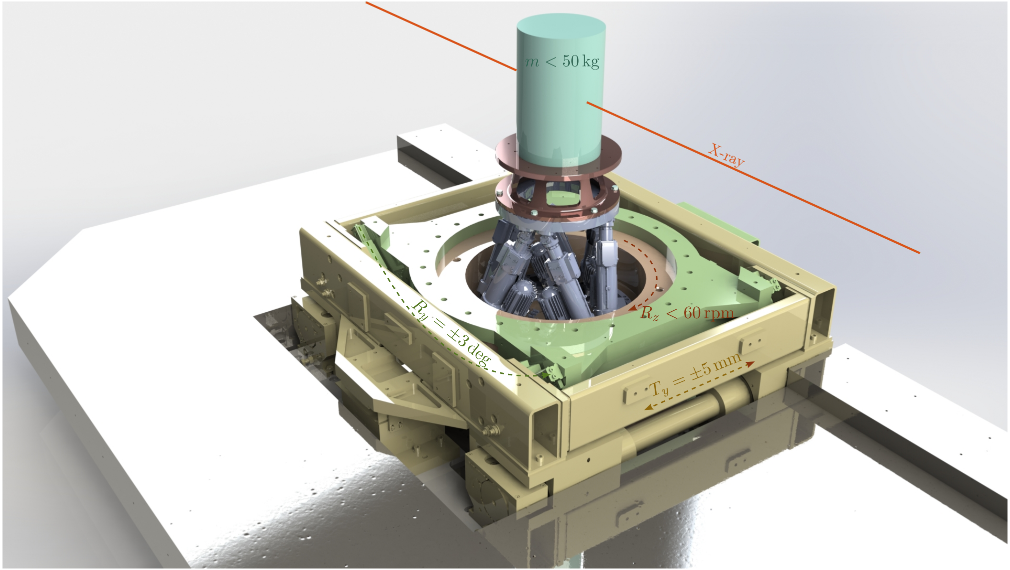
[3]BEAMS Department, Free University of Brussels, Belgium

Precision Mechatronics Laboratory

ESRF The European Synchrotron

MEDSI CHICAGO 2020

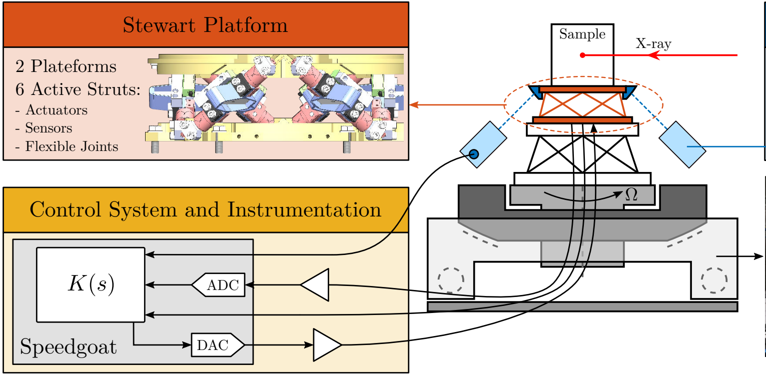
The ID31 Micro Station

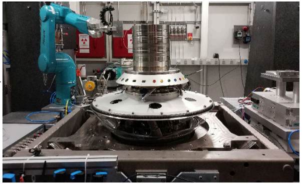


Introduction - The Nano Active Stabilization System

Objective: Improve the position accuracy from $\approx 10\,\mu m$ down to $\approx 10\,nm$

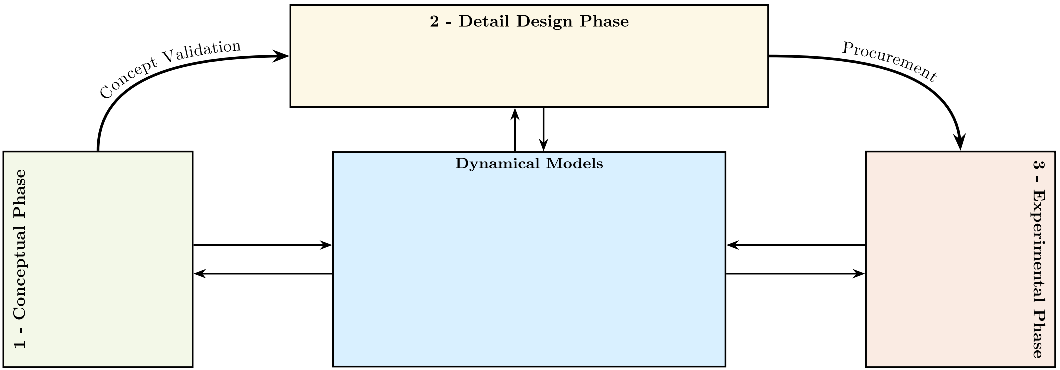
Design approach: "Model based design" / "Predictive Design"



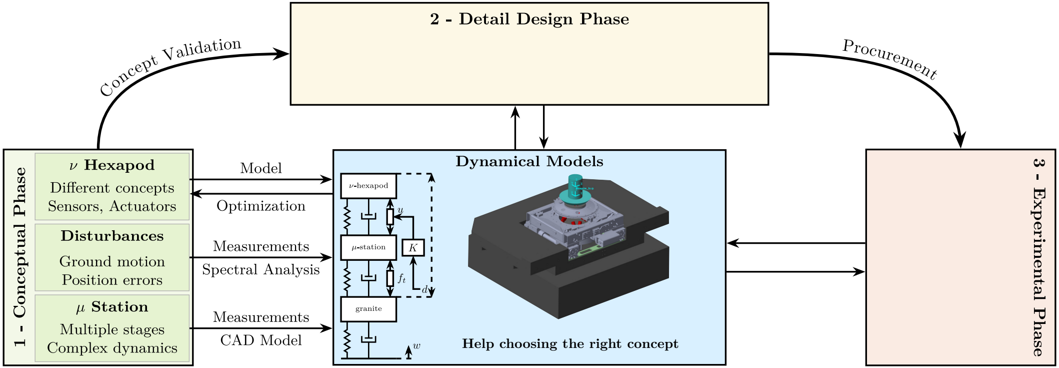


ID31 Micro-Station

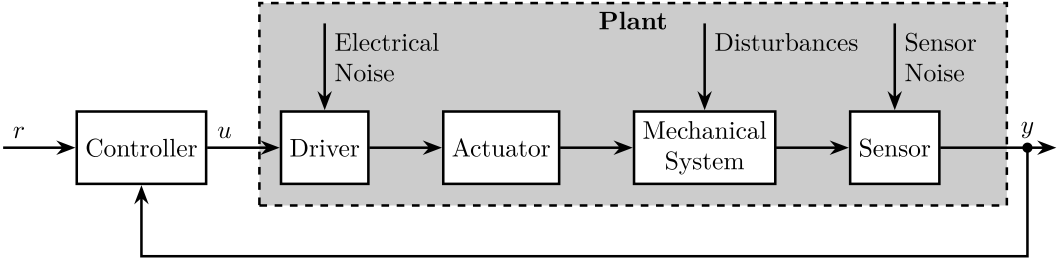
Overview of the Mechatronic Approach - Model Based Design



Outline - Conceptual Phase



Feedback Control - The Control Loop



Why Feedback?

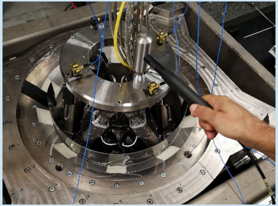
- Model uncertainties
- Unknown disturbances

Every elements can limit the performances

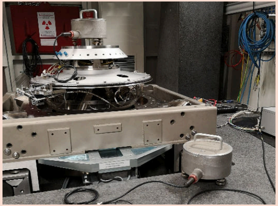
- Drivers, Actuators, Sensors
- Mechanical System
- Controller

Noise Budgeting and Required Control Bandwidth

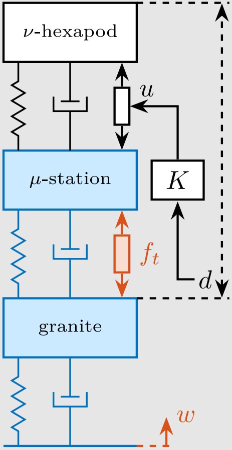
Dynamical Identification



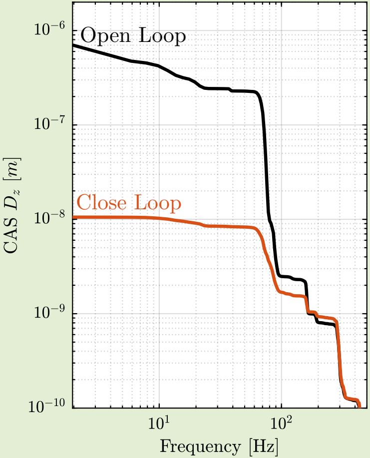
Disturbance Measurements



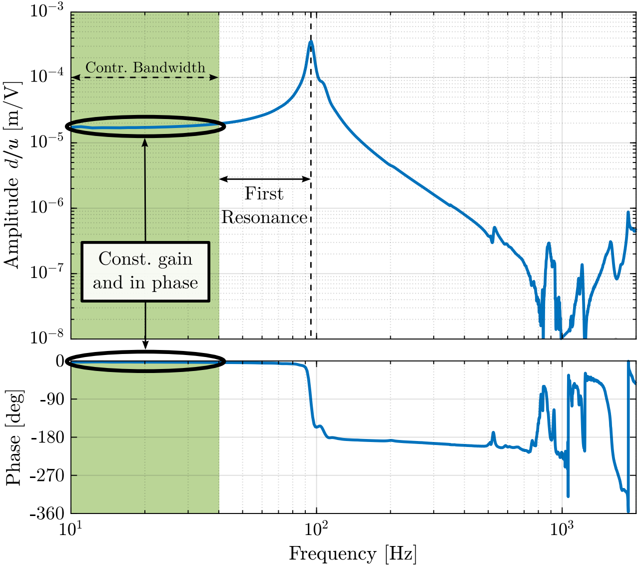
Mass-Spring-Damper Model

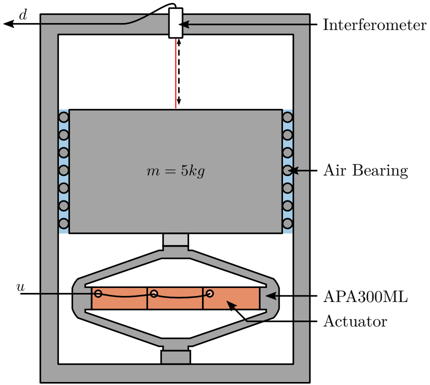


Noise Budgeting



Limitation of the Controller Bandwidth?

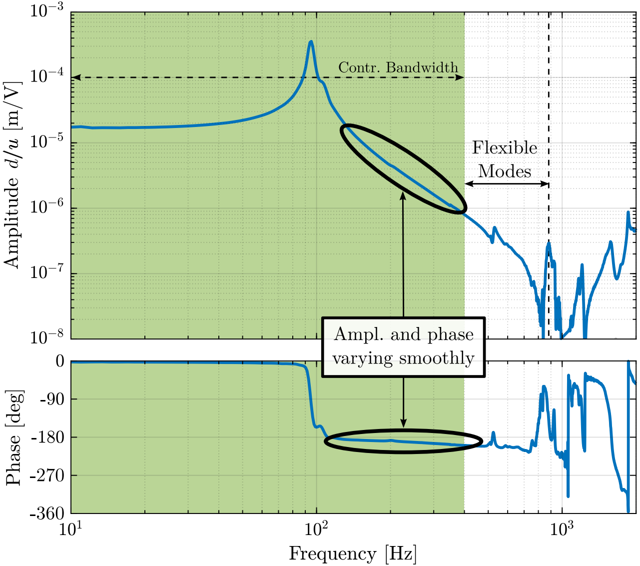


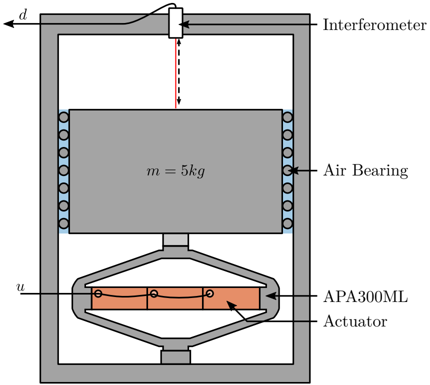


Typical Approach

"As stiff as possible"
Simple controller (e.g. PID)

Limitation of the Controller Bandwidth?

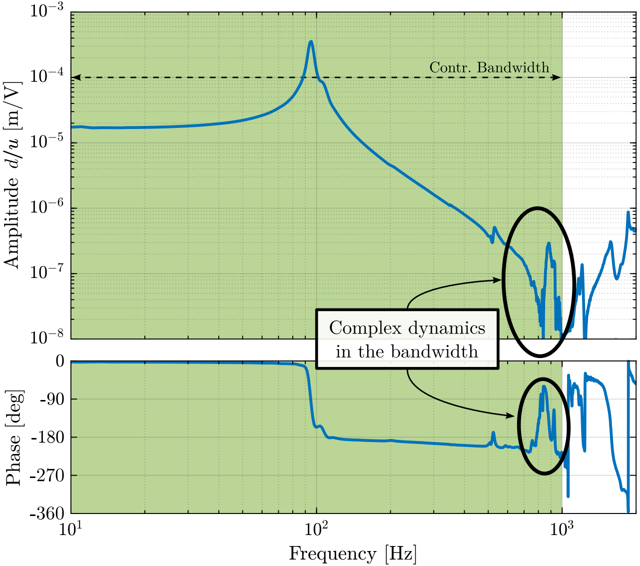


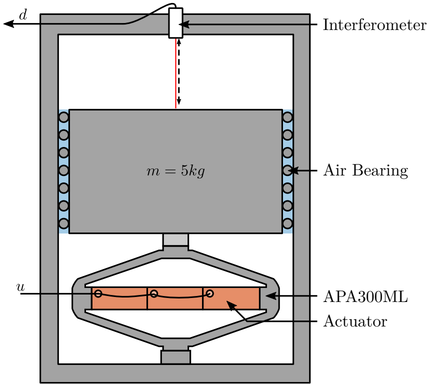


Alternative Approach

Limited by complex dynamics
Model based controller

Limitation of the Controller Bandwidth?

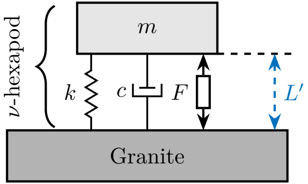


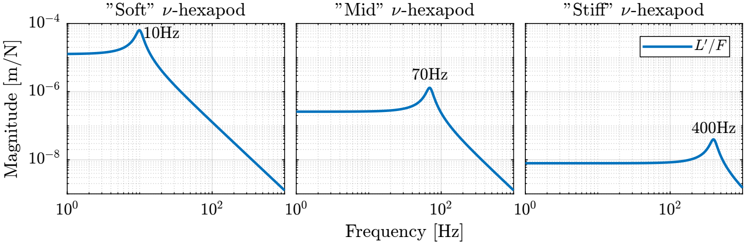


Next-Gen Systems

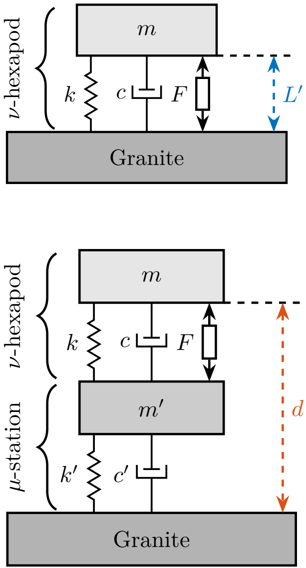
Active research topic
Complex controllers

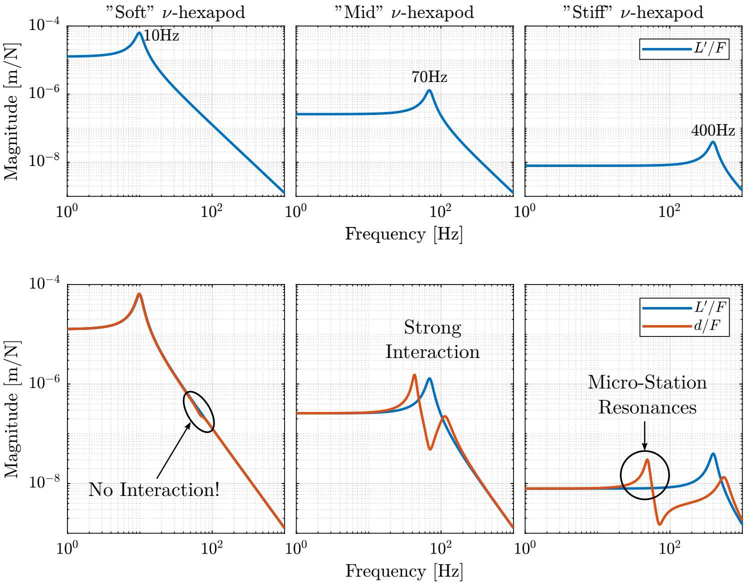
Soft or Stiff ν-hexapod ? Interaction with the μ-station



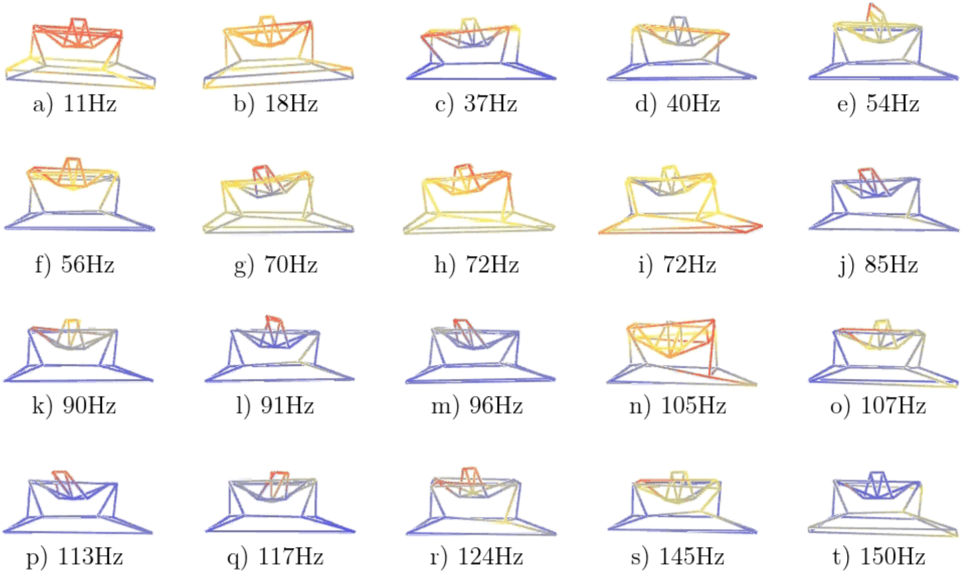


Soft or Stiff ν-hexapod ? Interaction with the μ-station





Complexity of the Micro-Station Dynamics (Model Analysis)



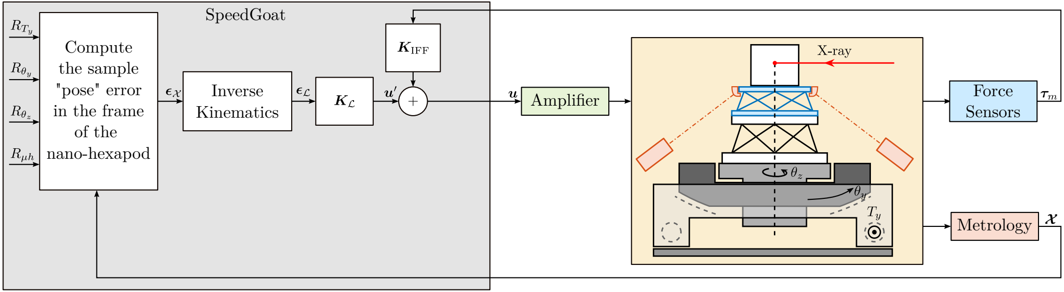
a) 11Hz b) 18Hz c) 37Hz d) 40Hz e) 54Hz

f) 56Hz g) 70Hz h) 72Hz i) 72Hz j) 85Hz

k) 90Hz l) 91Hz m) 96Hz n) 105Hz o) 107Hz

p) 113Hz q) 117Hz r) 124Hz s) 145Hz t) 150Hz

Control Strategy: HAC-LAC



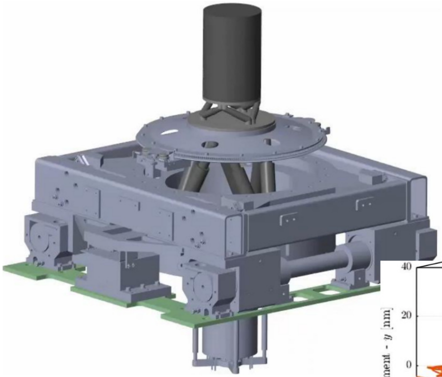
Low Authority Control

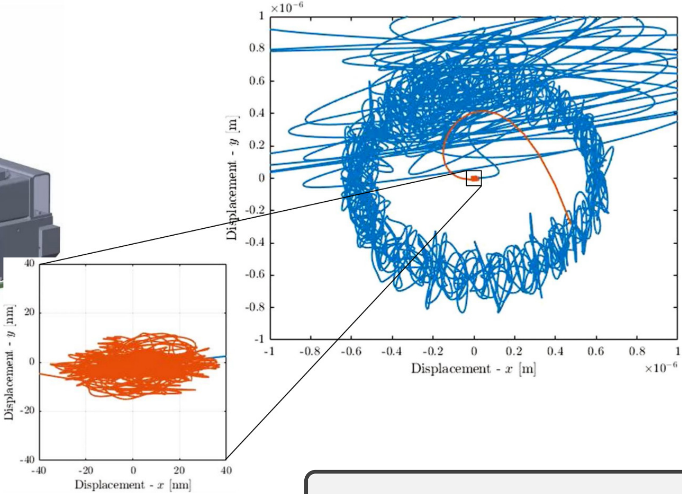
- Collocated sensors/actuators
- Guaranteed Stability
- Adds damping
- $\searrow$ vibration near resonances

High Authority Control

- Position sensors
- Complex dynamics
- $\searrow$ vibration in the bandwidth
- Use transformation matrices

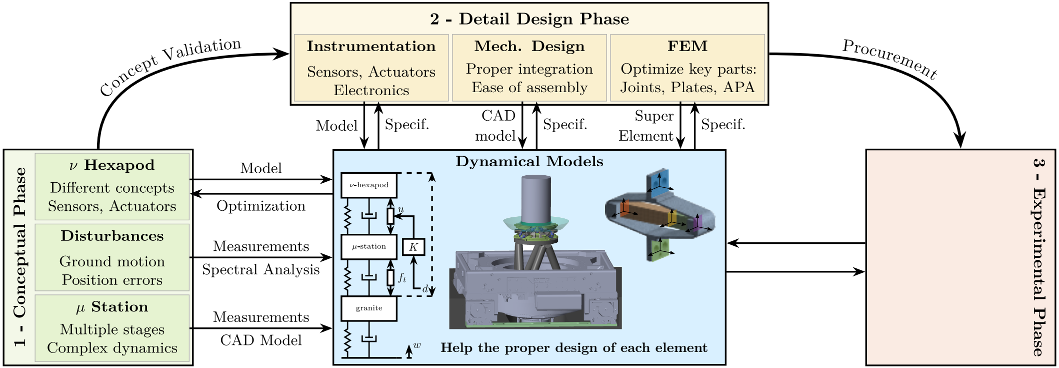
Multi-Body Models - Simulations



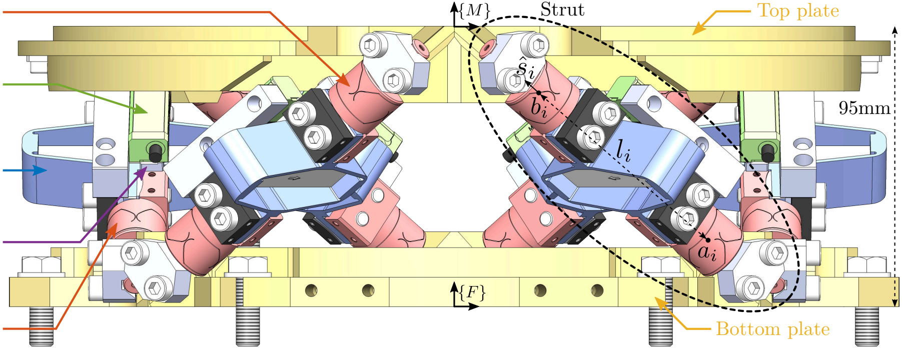


Validation of the concept

Outline - Detail Design Phase



Nano-Hexapod Overview - Key elements



General Specifications

- Flexible modes as high as possible
- Only flexible elements (no backlash, play, etc.)
- Integrated Force Sensor and Displacement Sensor
- Predictable dynamics

Choice of Actuator and Flexible Joint Design

Characteristic	Specs	Doc.
Axial Stiff.	≈2 N/µm	1.8 N/µm
Sufficient Stroke	>100 µm	368 µm
Height	<50 mm	30 mm
High Resolution	<5 nm	3 nm

Characteristic	Specs	FEM
Axial Stiff.	>100 N/µm	94
Bending Stiff.	<100 Nm/rad	5
Torsion Stiff.	<500 Nm/rad	260
Bending Stroke	>1 mrad	20

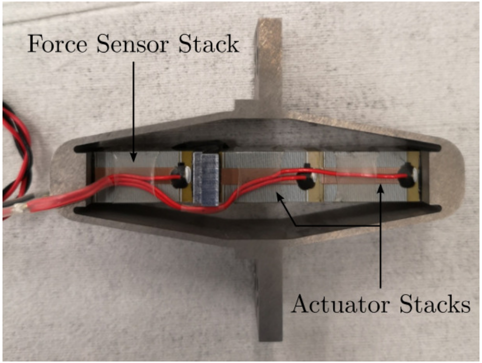


Fig.: Picture of the APA300ML

Fig.: Picture of the joint

Instrumentation

Fig.: PiezoDrive - PD200 Amplifier

Fig.: Renishaw - Vionic Encoder

Fig.: Speedgoat - Target Machine

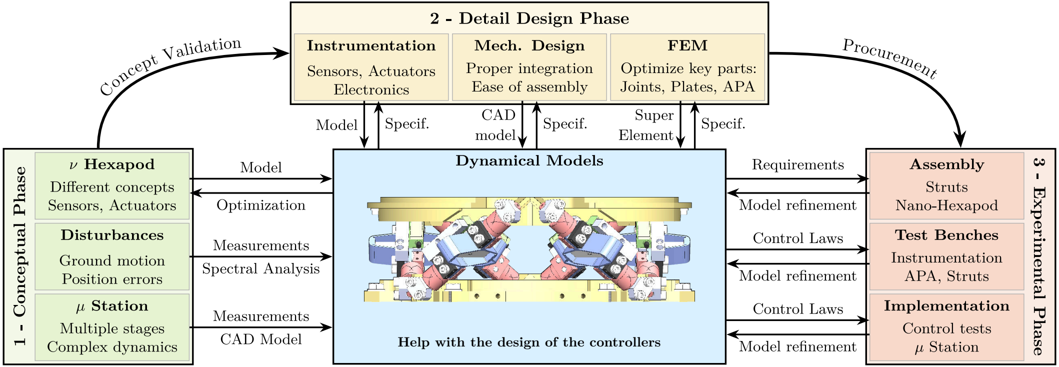
Characteristics	Manual
Gain	20
Noise	0.7 mV rms
Small Signal BW	7.4 kHz
Large Signal BW	300 Hz

Characteristics	Manual
Range	Ruler length
Resolution	2.5 nm
Sub-Divisional Error	$< \pm$ 15 nm
Bandwidth	$>$5 kHz

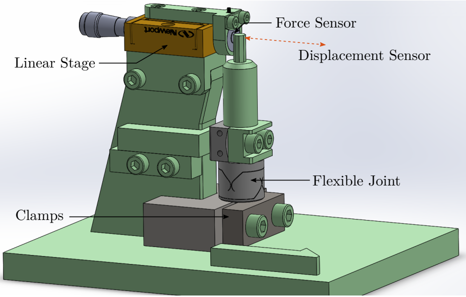
Characteristics	Manual
ADC (x16)	16bit, $\pm$10 V
DAC (x8)	16bit, $\pm$10 V
Digital I/O (x30)	$< \pm$ 15 nm
Sampling Freq.	$>$10 kHz

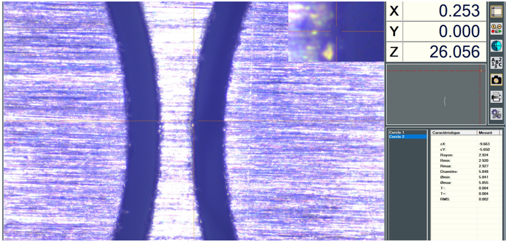
All elements could be chosen/design based on the models

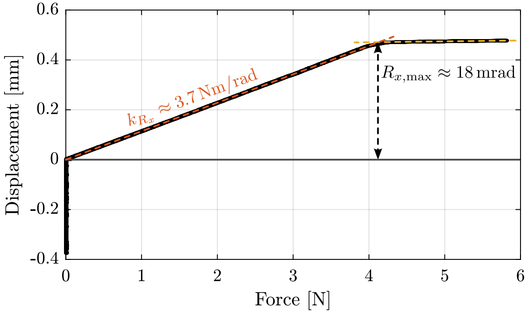
Outline - Experimental Phase



Flexible Joints - Measurements



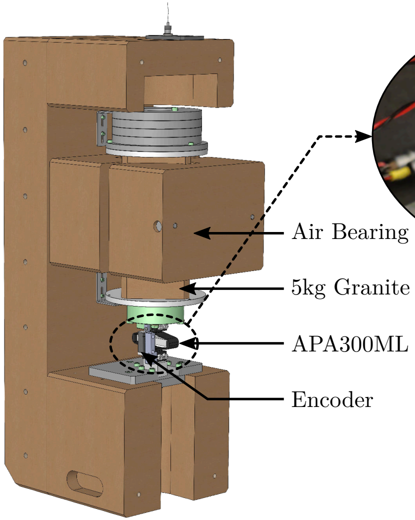


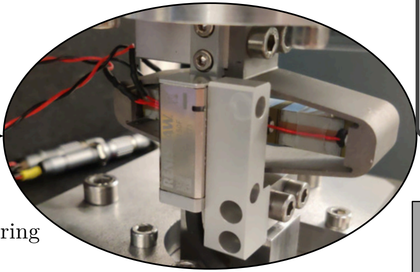


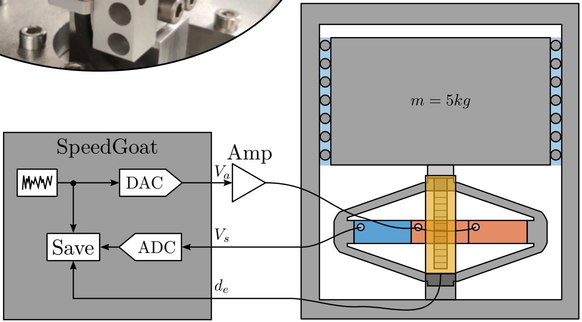
Amplified Piezoelectric Actuator - Test Bench

Goals

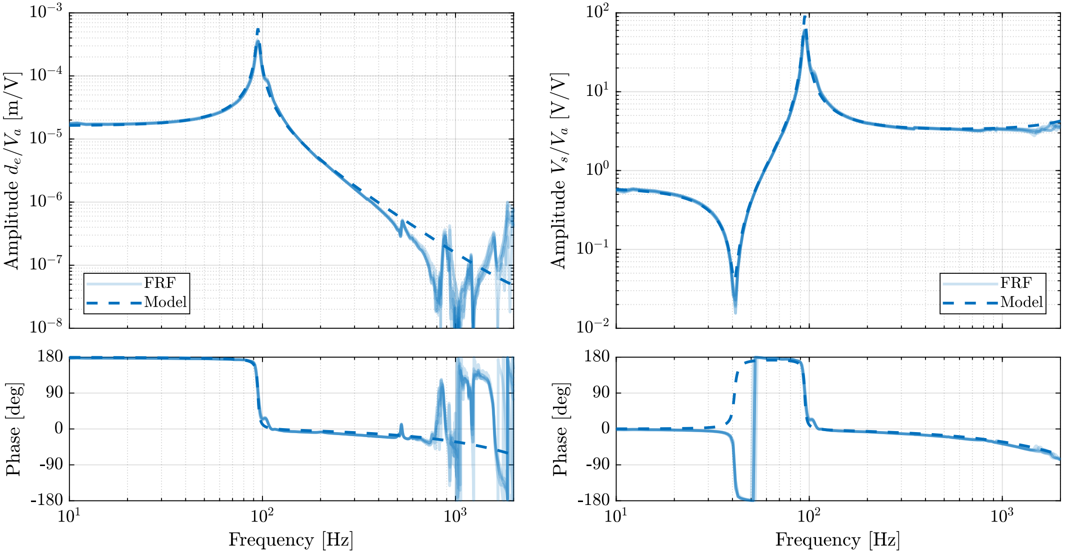
- Identify Dynamics
- Tune APA Model
- Test IFF



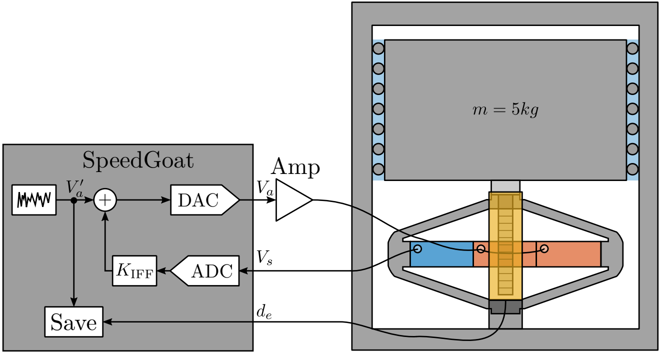


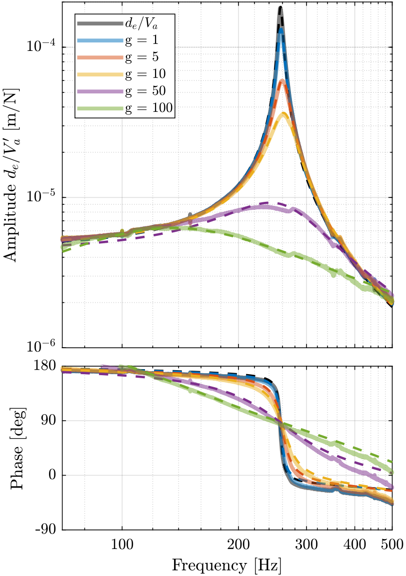


Amplified Piezoelectric Actuator - Extracted Model



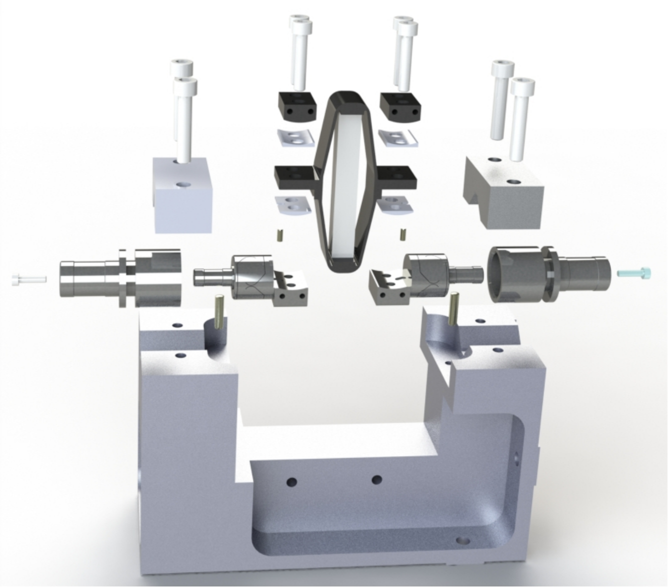
Amplified Piezoelectric Actuator - Integral Force Feedback

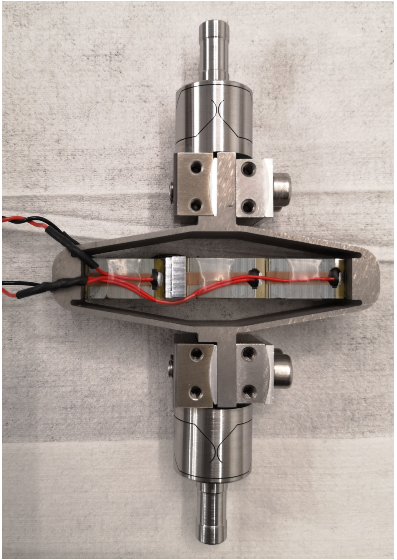




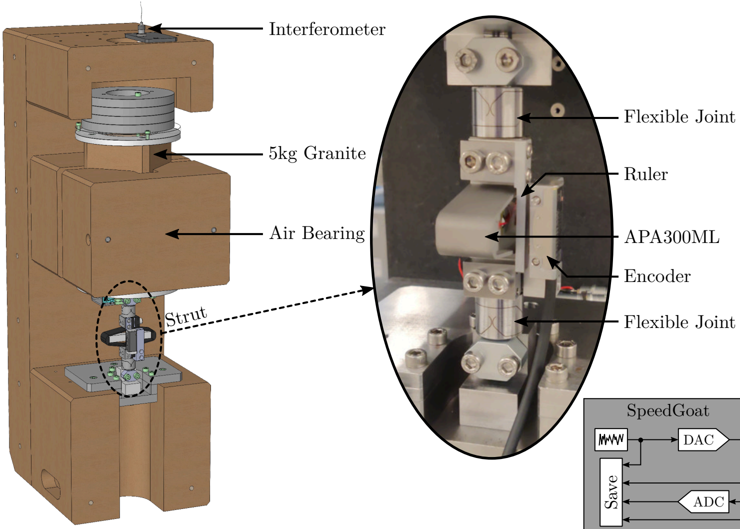
$$K_{\mathsf{IFF}}(s) = \frac{g}{s}$$

Strut - Mounting Tool



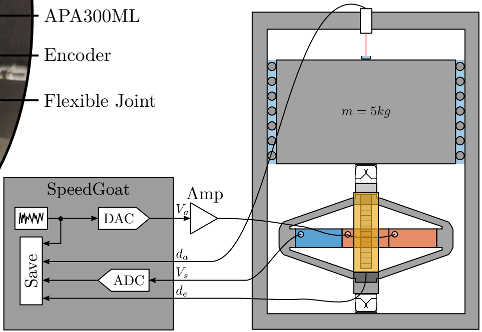


Strut - Dynamical Measurements

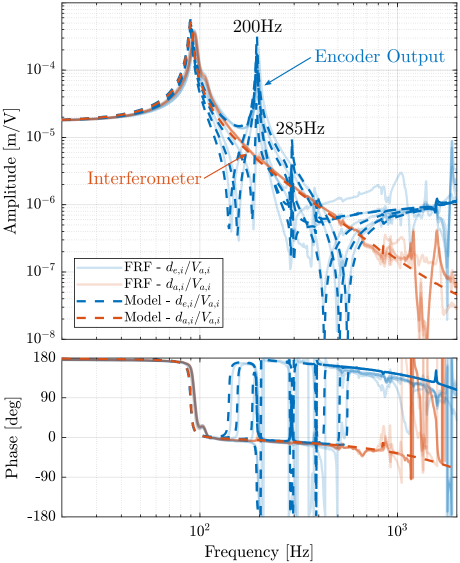


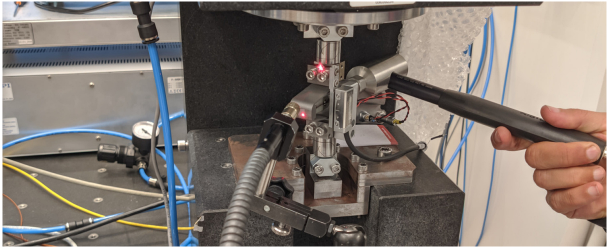
Goals

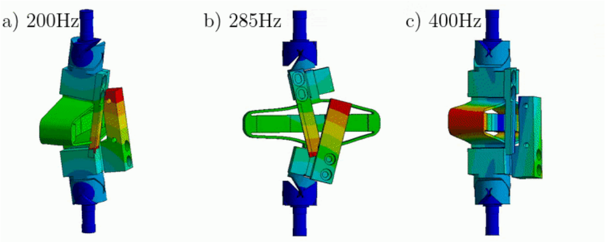
- Identify Dynamics
- Tune Model
- Flexible joints effects
- Encoder effect



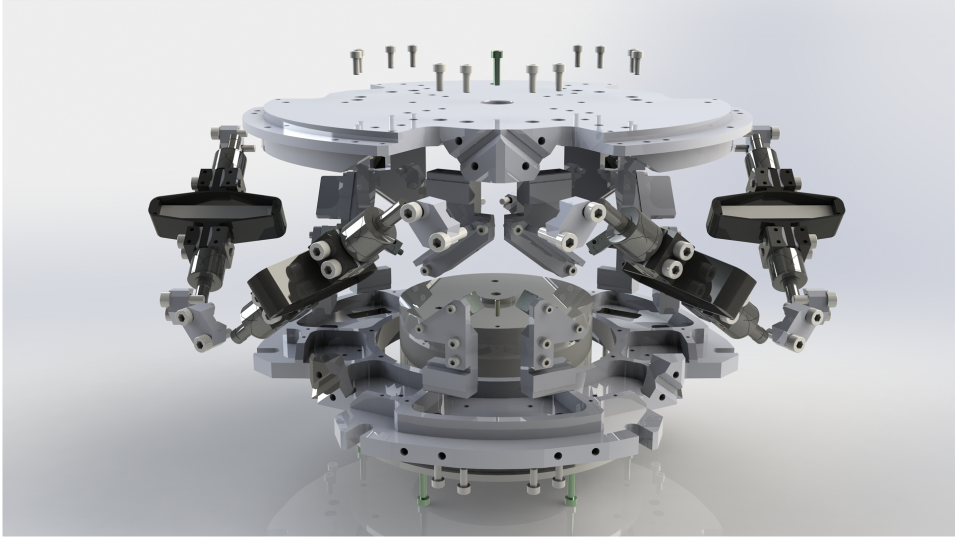
Strut - Encoders Output and Spurious Modes



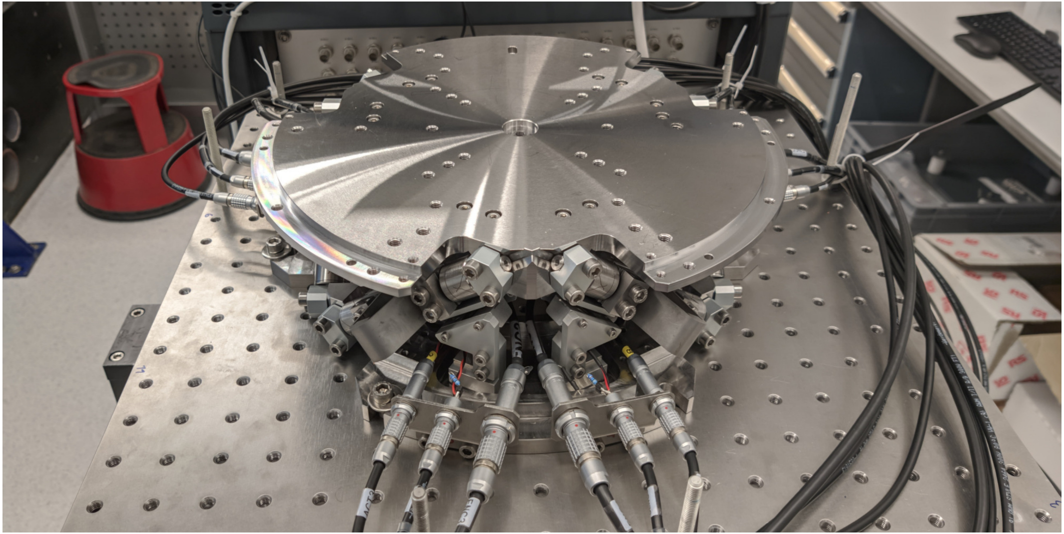




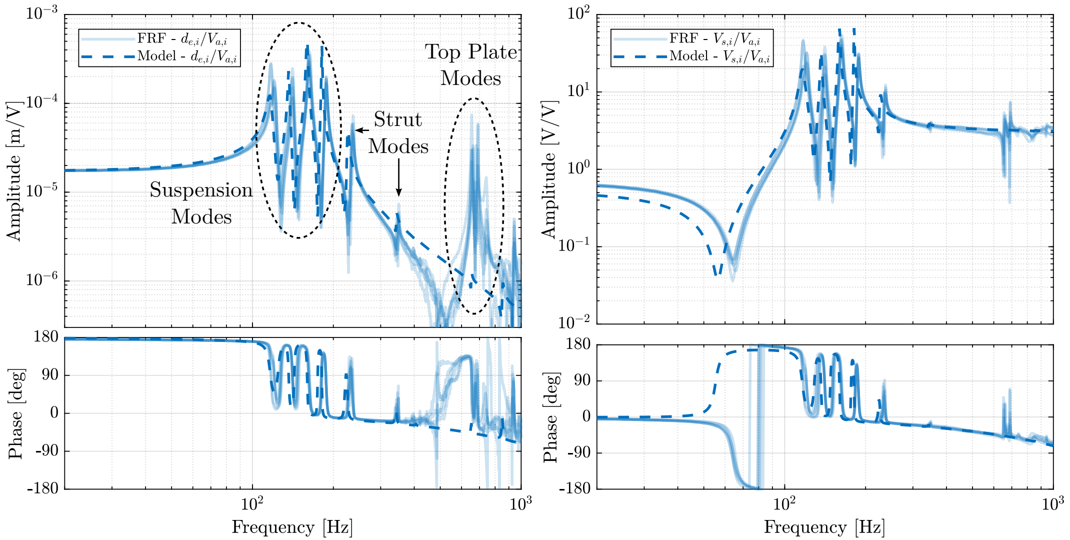
Nano-Hexapod Mounting Tool



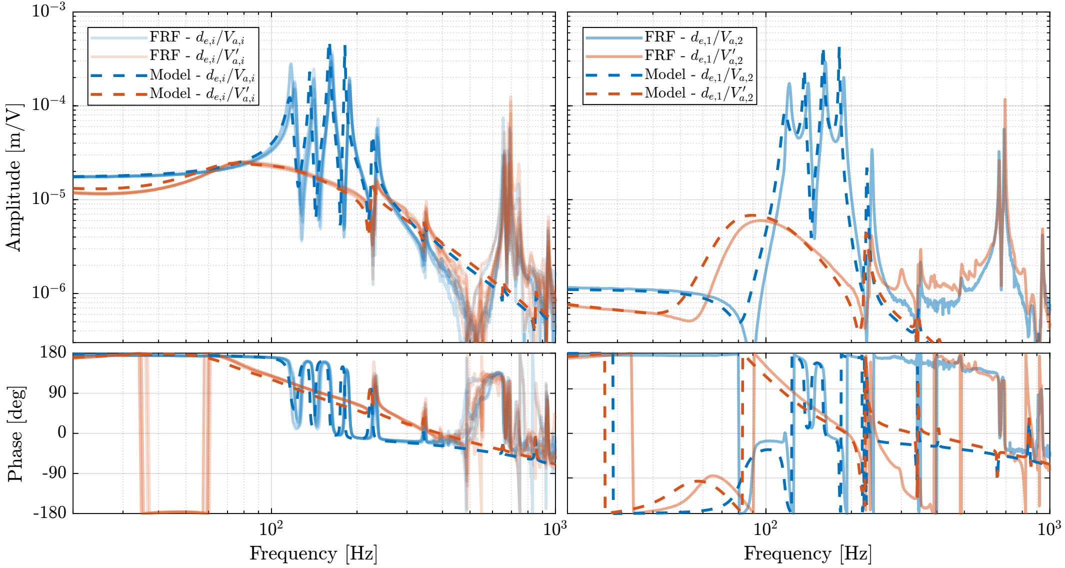
Mounted Nano-Hexapod



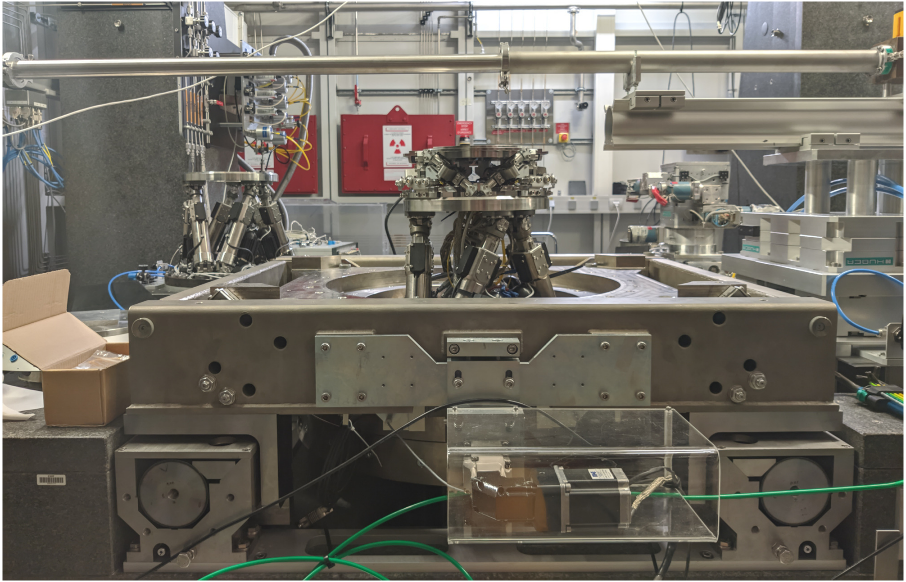
Nano-Hexapod - Identified Dynamics



Nano-Hexapod - Damped Dynamics



The Nano-Hexapod on top of the Micro-Station



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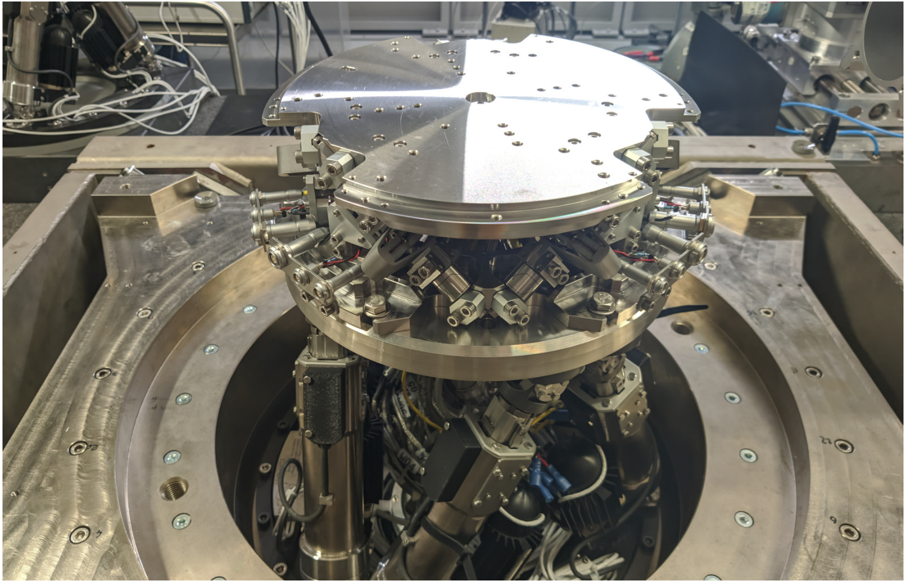


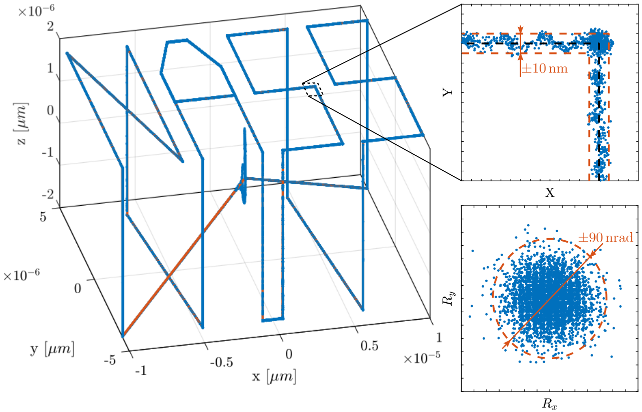
Conclusion

Mechatronics Approach:

- Use of several models
- Predictive design
- Beneficial in terms of: cost, delays, performances

Future Work:

- Optimal/Robust control
- Control Test Bench
- Implementation on ID31



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