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

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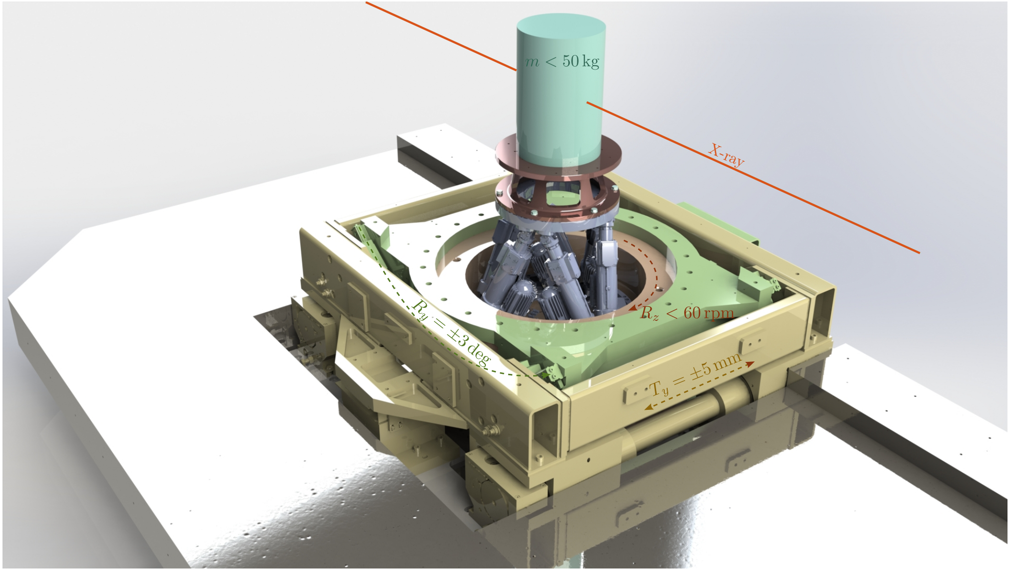
Precision Mechatronics Laboratory

ESRF The European Synchrotron

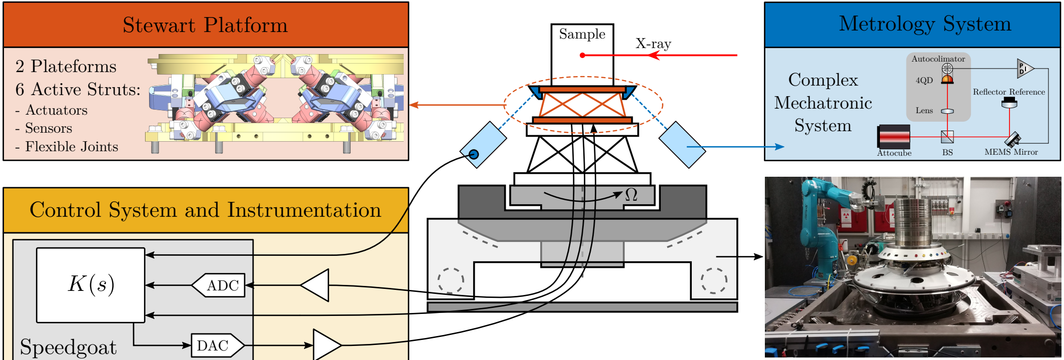
MEDSI CHICAGO 2020

The ID31 Micro Station



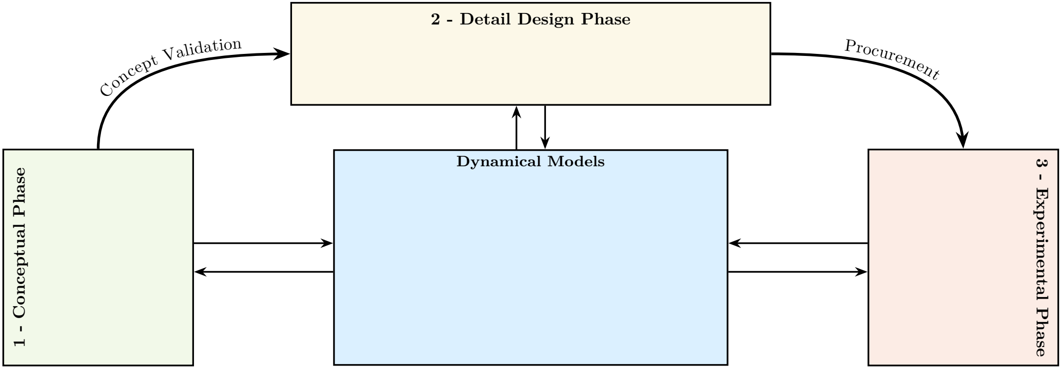
Introduction - The Nano Active Stabilization System

Objective: Improve the position accuracy from $\approx 10\,\mu m$ down to $\approx 10\,nm$
Design approach: “Model based design” / “Predictive Design”

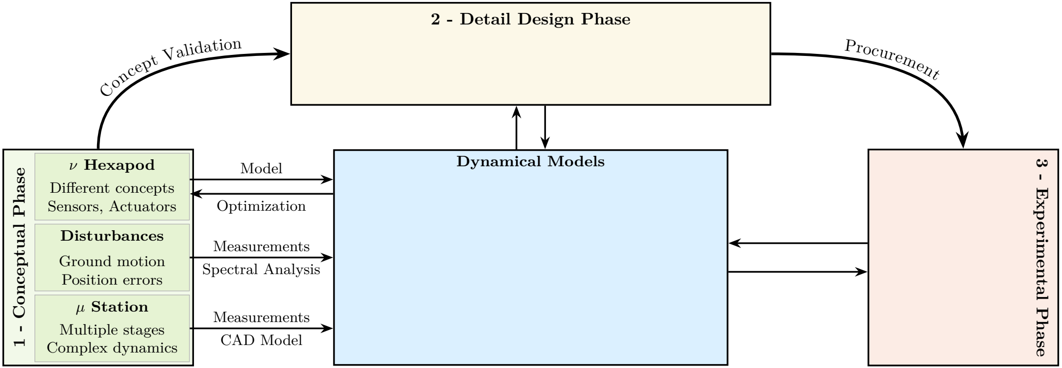


ID31 Micro-Station

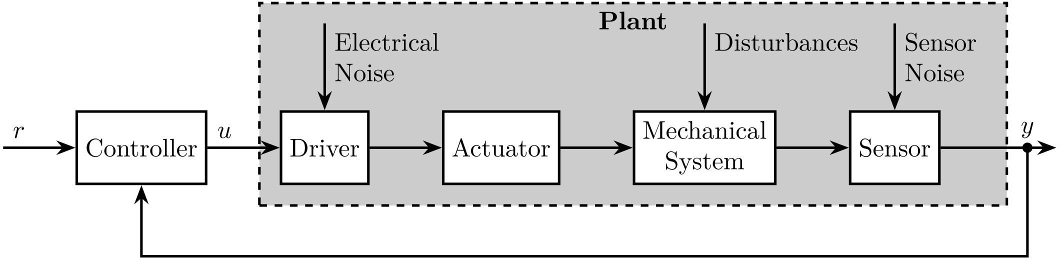
Overview of the Mechatronic Approach - Model Based Design



Outline - Conceptual Phase



Feedback Control - The Control Loop



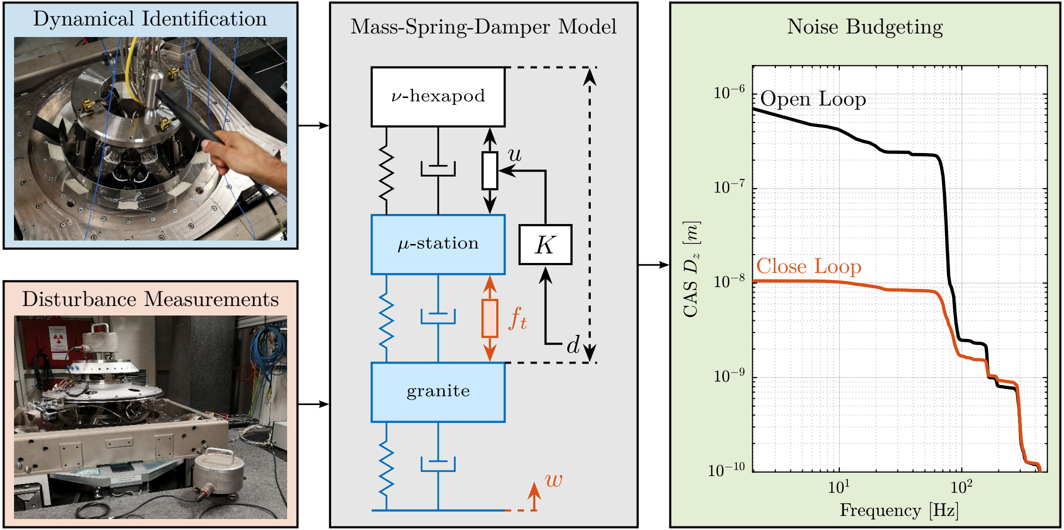
Why Feedback?

- Model uncertainties
- Unknown disturbances

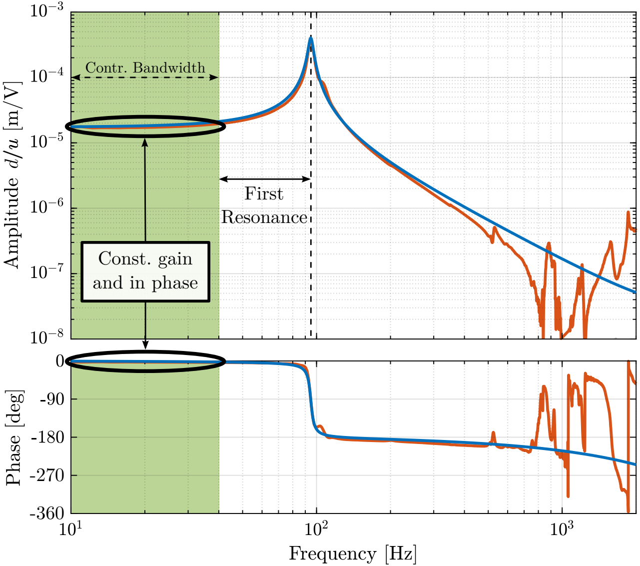
Every elements can limit the performances

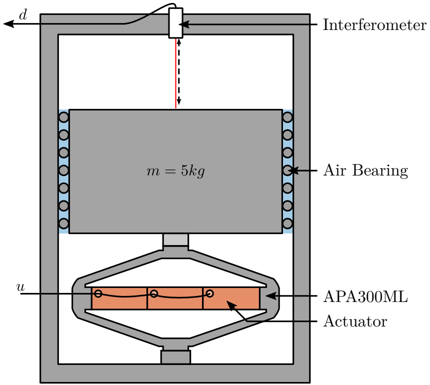
- Drivers, Actuators, Sensors
- Mechanical System
- Controller

Noise Budgeting and Required Control Bandwidth



Limitation of the Controller Bandwidth?

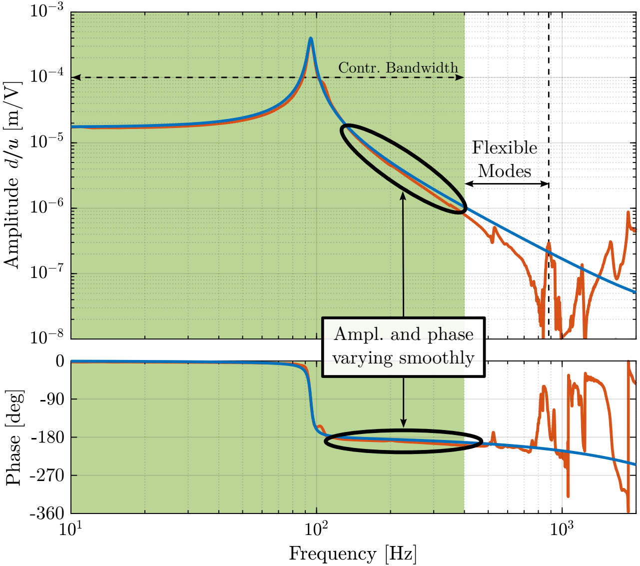


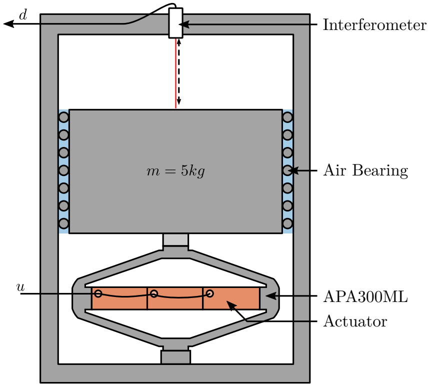


Typical Approach

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

Limitation of the Controller Bandwidth?

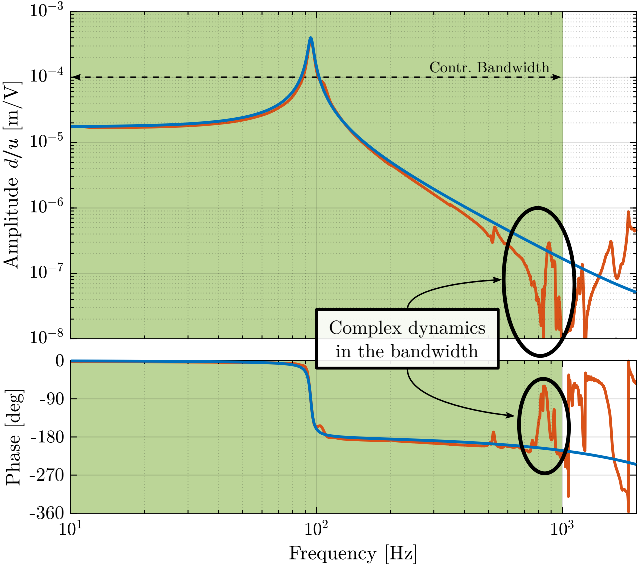


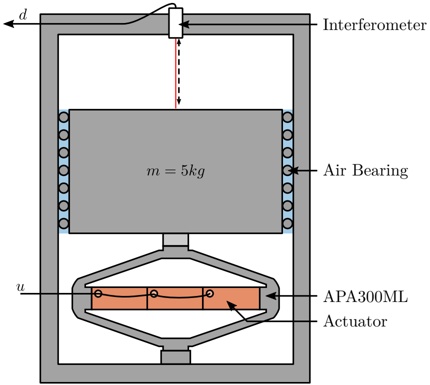


Alternative Approach

Limited by complex dynamics
Model based controller

Limitation of the Controller Bandwidth?

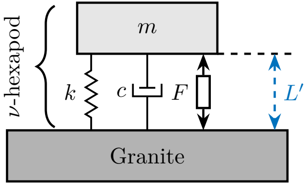


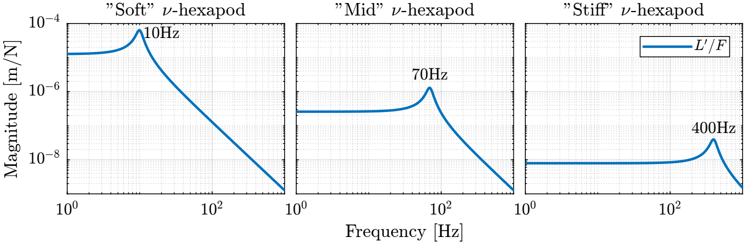


Next-Gen Systems

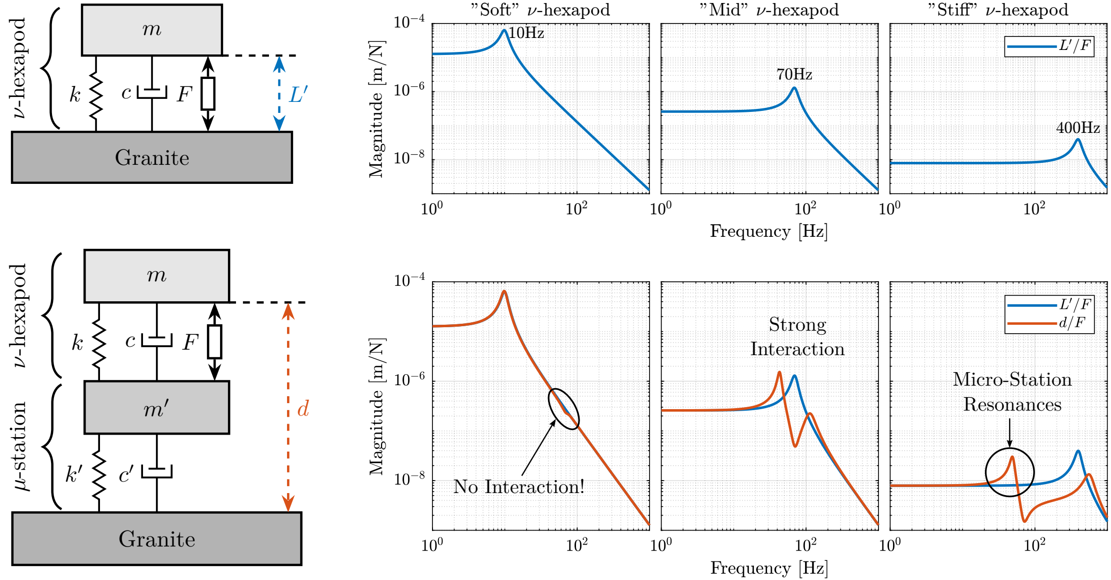
Active research topic
Complex controllers

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

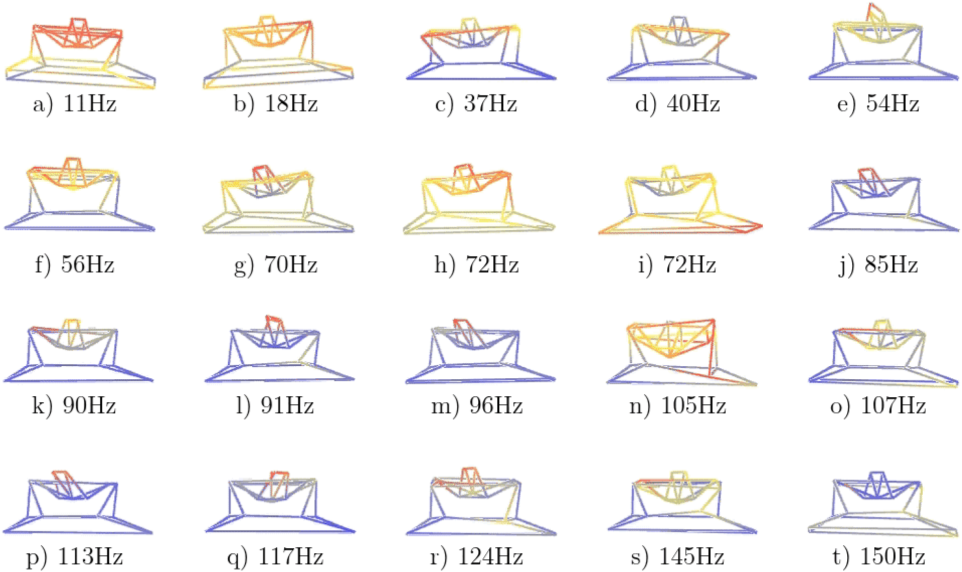




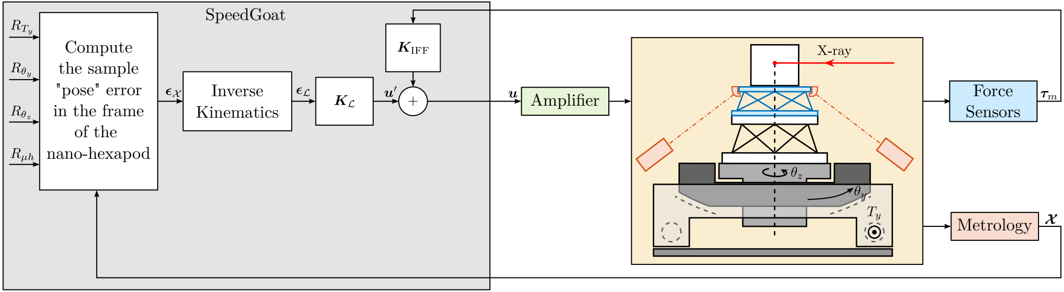
Soft or Stiff ν-hexapod ? Interaction with the μ-station



Complexity of the Micro-Station Dynamics (Model Analysis)



Control Strategy: HAC-LAC



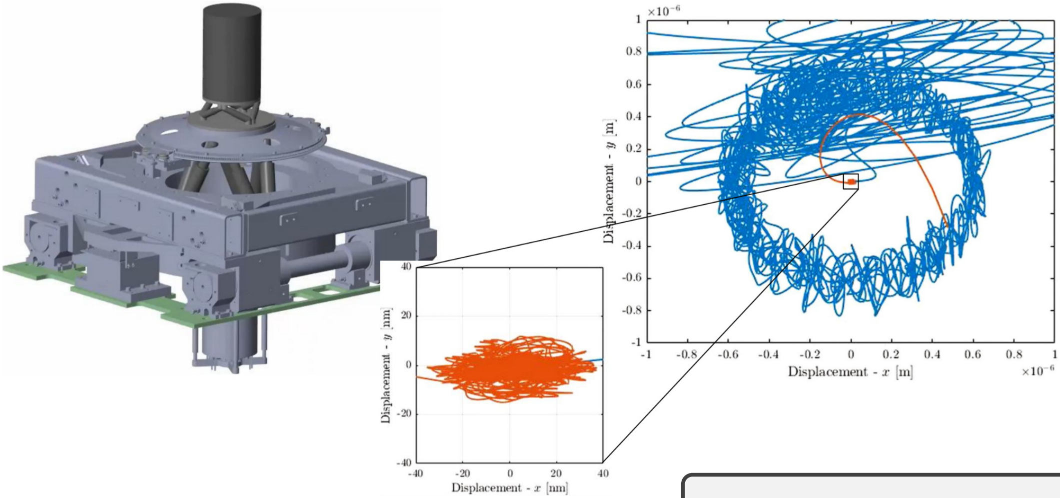
Low Authority Control

- Collocated sensors/actuators
- Guaranteed Stability
- Adds damping
- ↘ vibration near resonances

High Authority Control

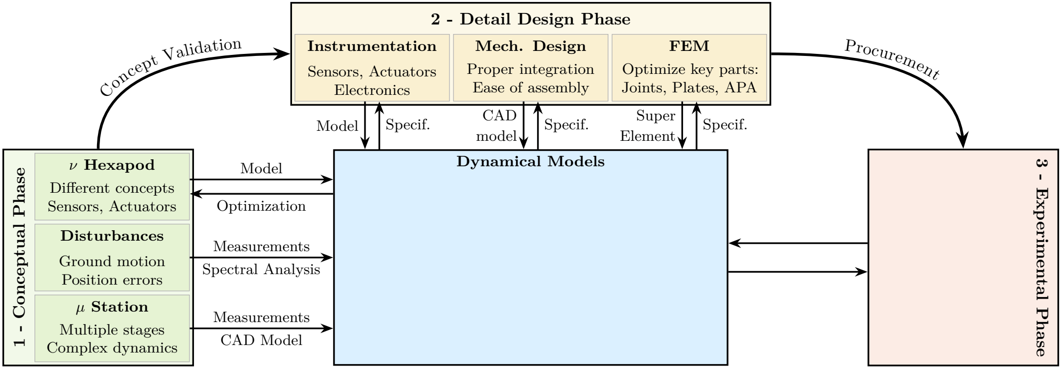
- Position sensors
- Complex dynamics
- ↘ vibration in the bandwidth
- Use transformation matrices

Multi-Body Models - Simulations

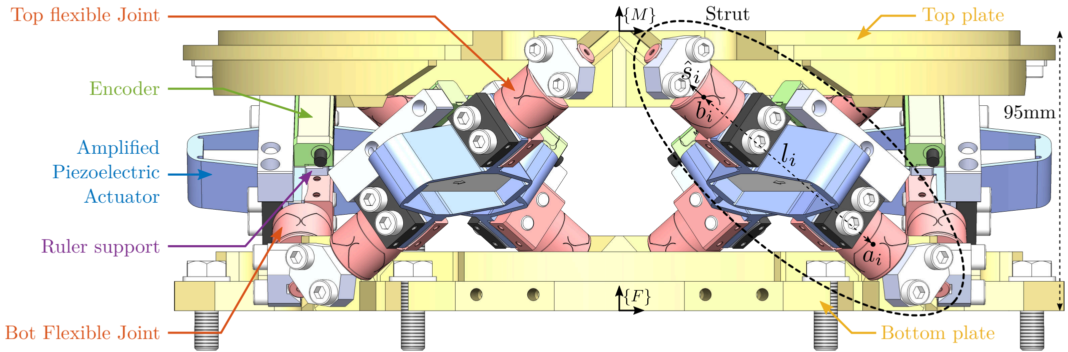


Validation of the concept

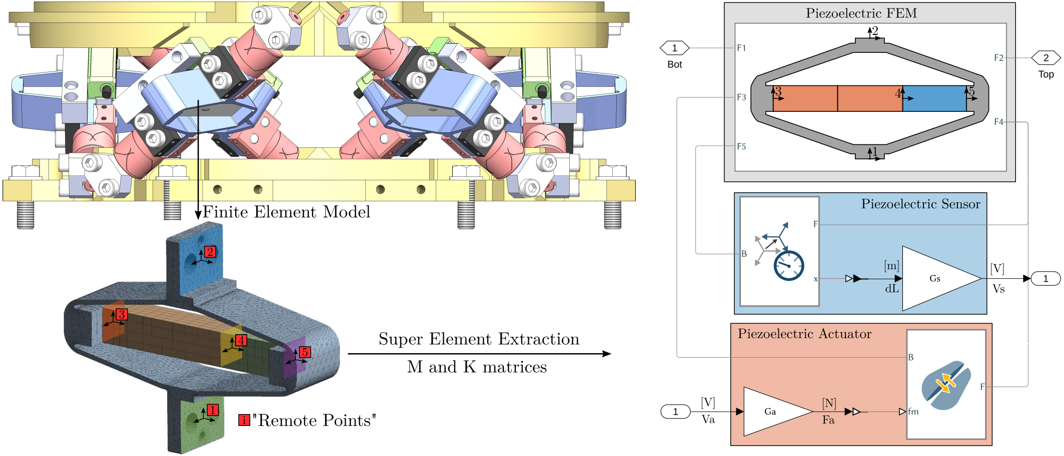
Outline - Detail Design Phase



Nano-Hexapod Overview - Key elements



Include Flexible Elements in a Multi-Body model



Choice of Actuator - Amplifier Piezoelectric Actuator

Characteristic	Specs	Doc.
Axial Stiff.	≈1 N/µm	1.8 N/µm
Sufficient Stroke	>100 µm	368 µm
Height	<50 mm	30 mm
High Resolution	<5 nm	3 nm

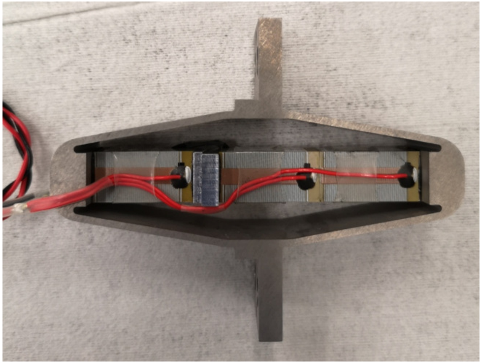


Fig.: Picture of the APA300ML

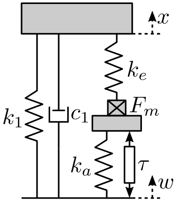


Fig.: 2-DoF Model

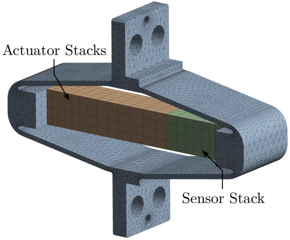


Fig.: APA Finite Element Model

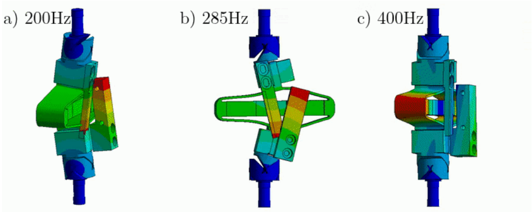


Fig.: Flexible Modes due to limited APA stiffness

Flexible Joints - Specifications and Optimization (link)

Goal	Stiffness	Specs	FEM	Measured
High DVF Damping	Axial	>100 N/µm	94	
Low Coupling	Bending	<100 Nm/rad	5	3.8
Low Coupling	Torsion	<500 Nm/rad	260	
Sufficient Stroke	Bending Stroke	>1 mrad	20	18

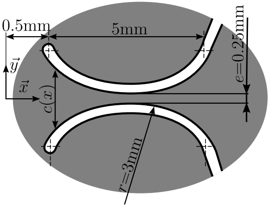


Fig.: Dimensions after optimization

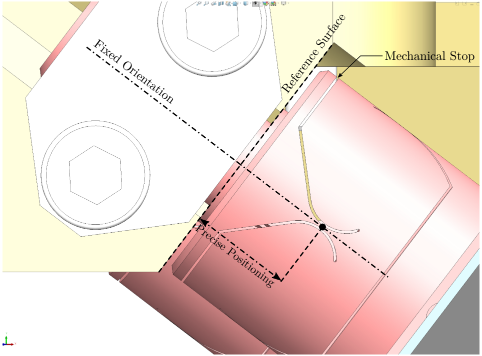


Fig.: Positioning of the top joint

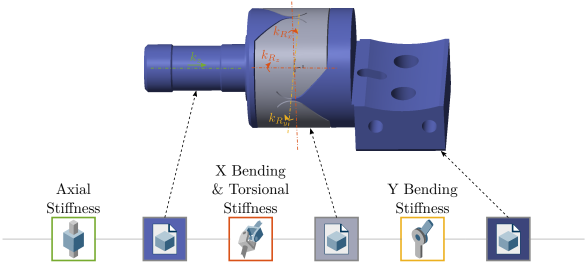
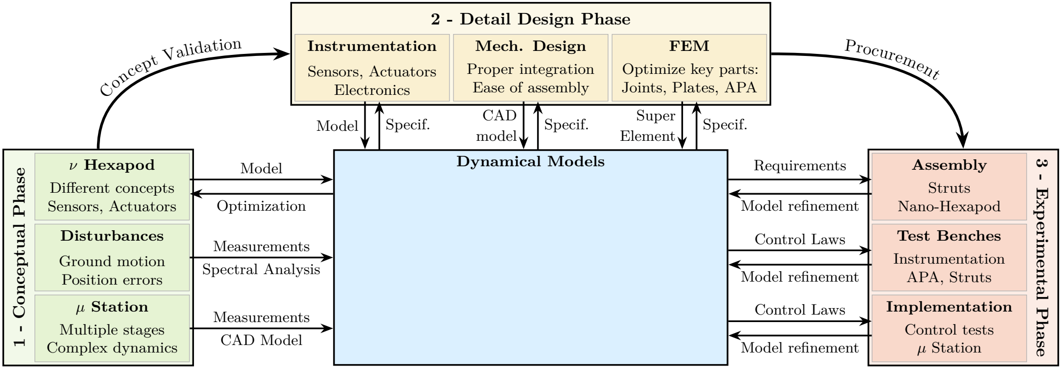


Fig.: Simscape Model

Instrumentation

- PD200 amplifier
- Encoders
- Speedgoat, DAC, ADC
- PEPU
- Attocube

Outline - Experimental Phase



Flexible Joints - Measurements

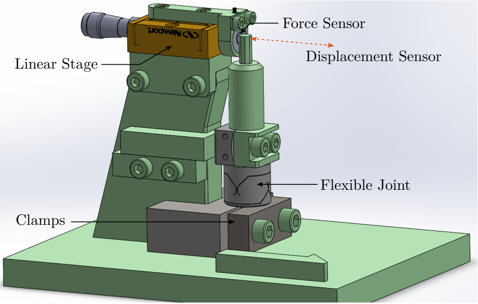


Fig.: Measurement bench

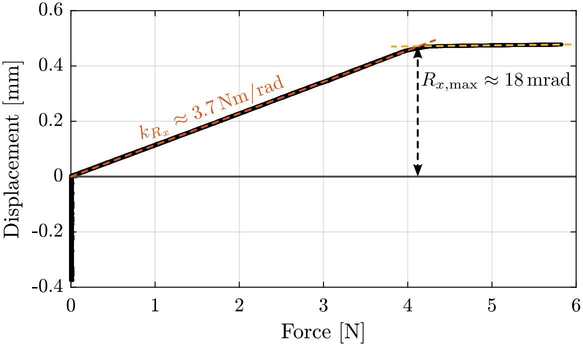
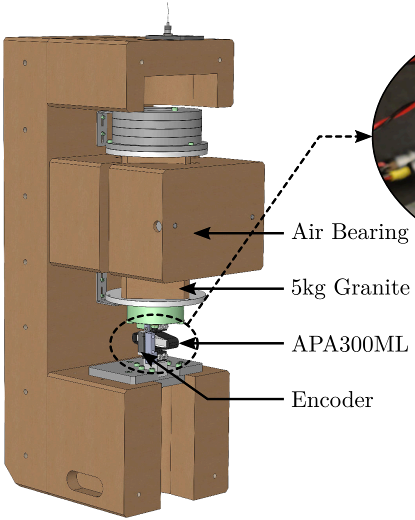
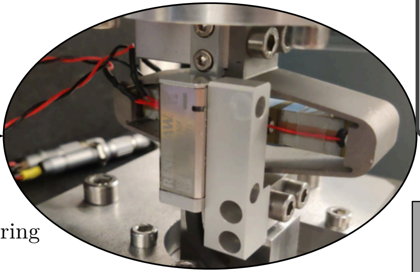


Fig.: Measured displacement and force

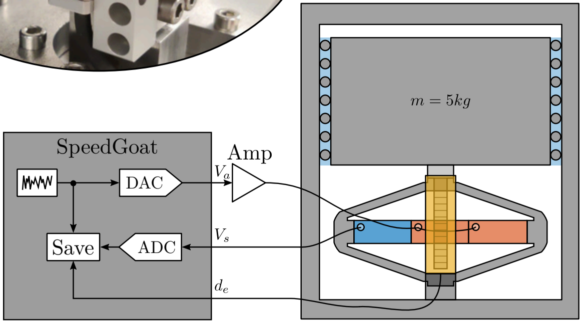
Amplified Piezoelectric Actuator - Test Bench



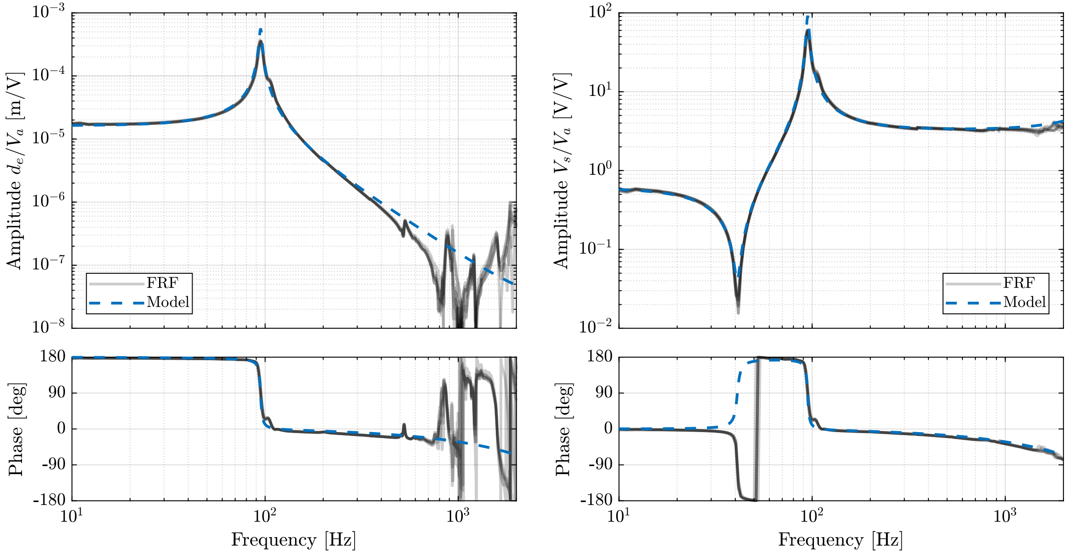


Goals

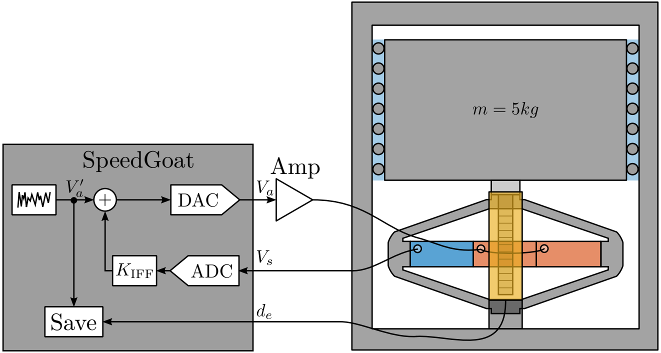
- Identify Dynamics
- Tune APA Model
- Test IFF



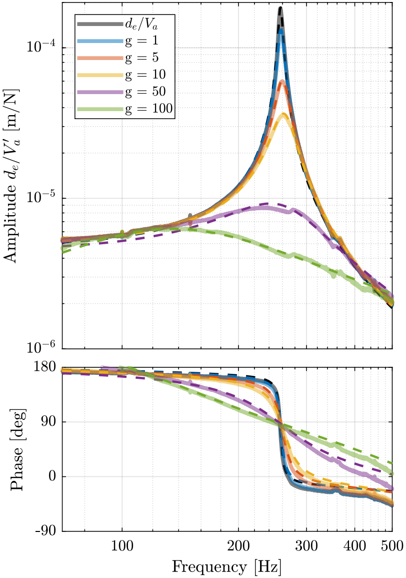
Amplified Piezoelectric Actuator - Extracted Model



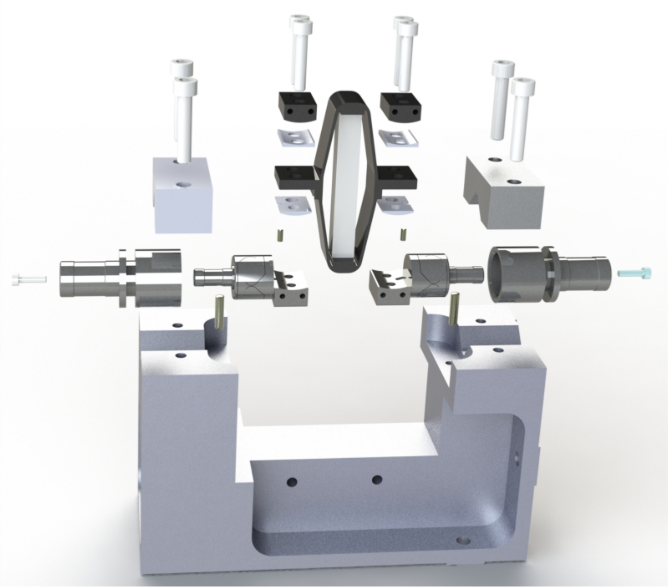
Amplified Piezoelectric Actuator - Integral Force Feedback

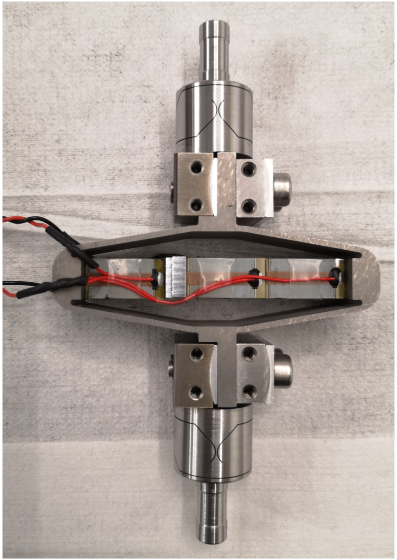


$$K_{\mathsf{IFF}}(s) = \frac{g}{s}$$

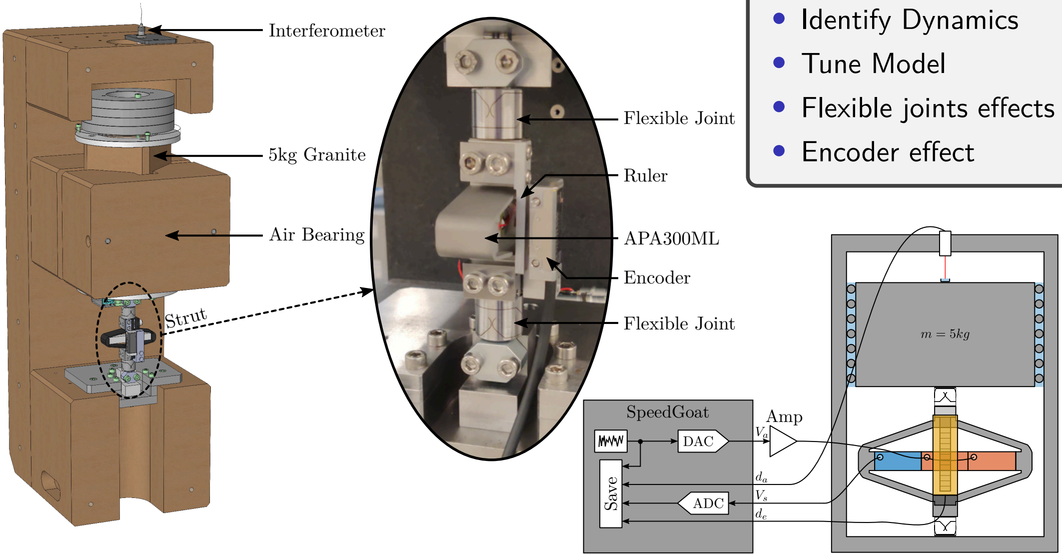


Strut - Mounting Tool





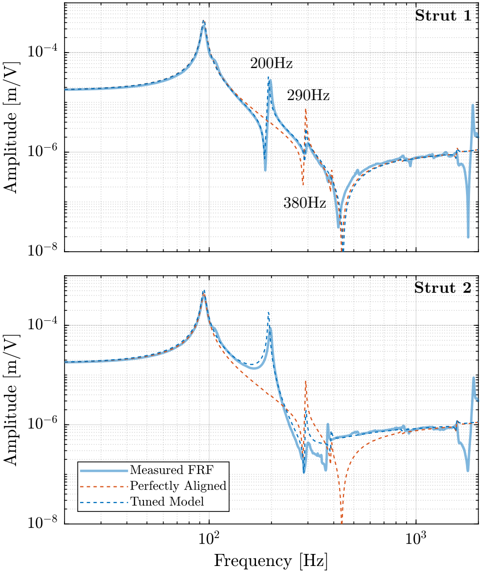
Strut - Dynamical Measurements

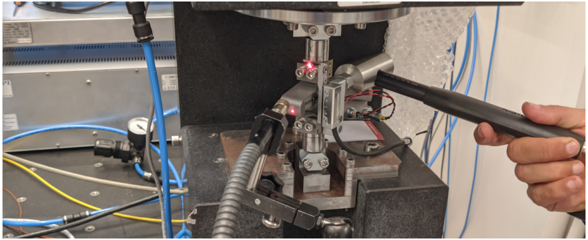


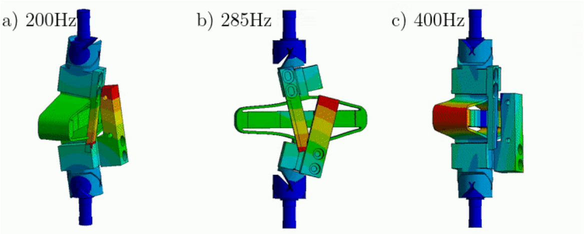
Goals

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

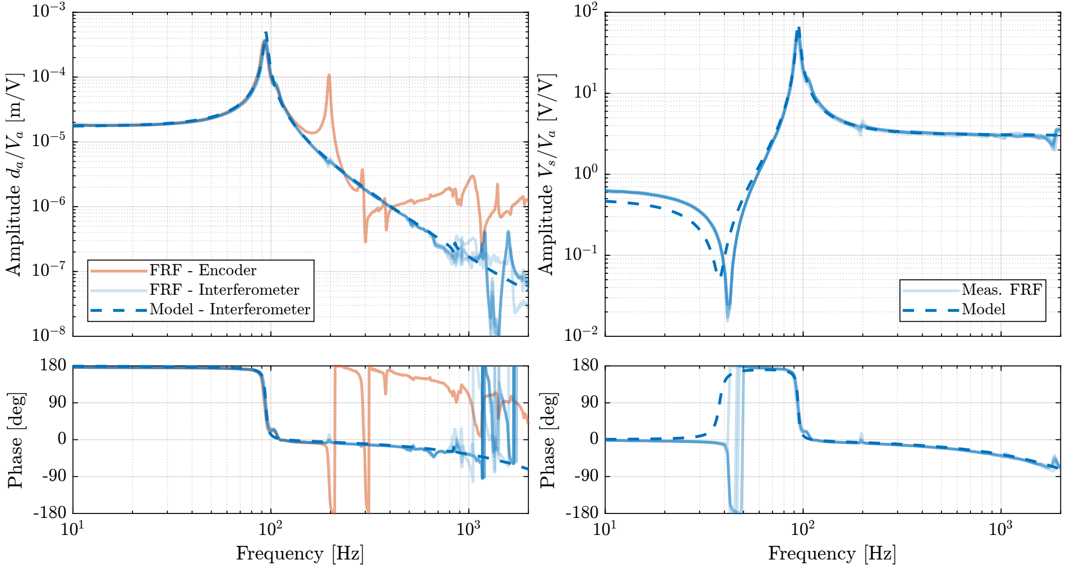
Strut - Encoders Output and Spurious Modes



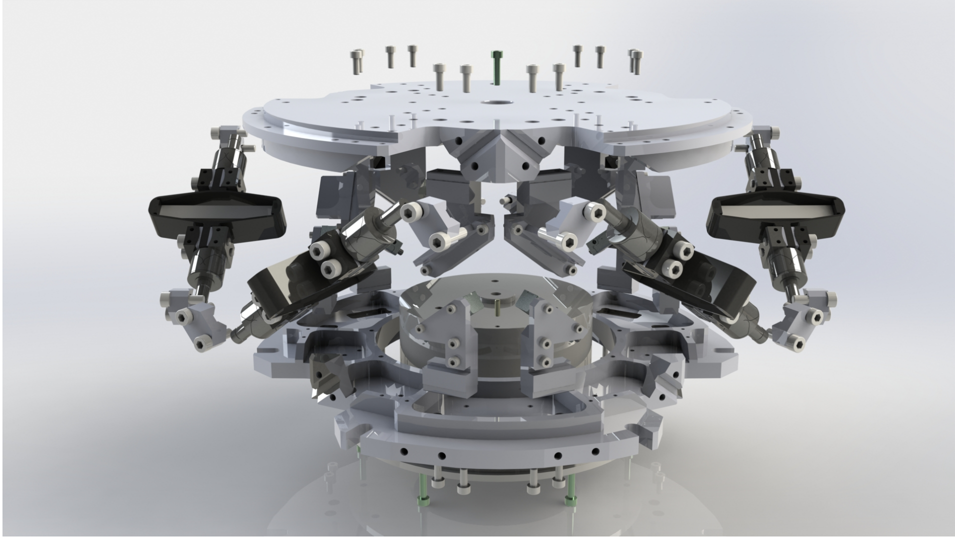




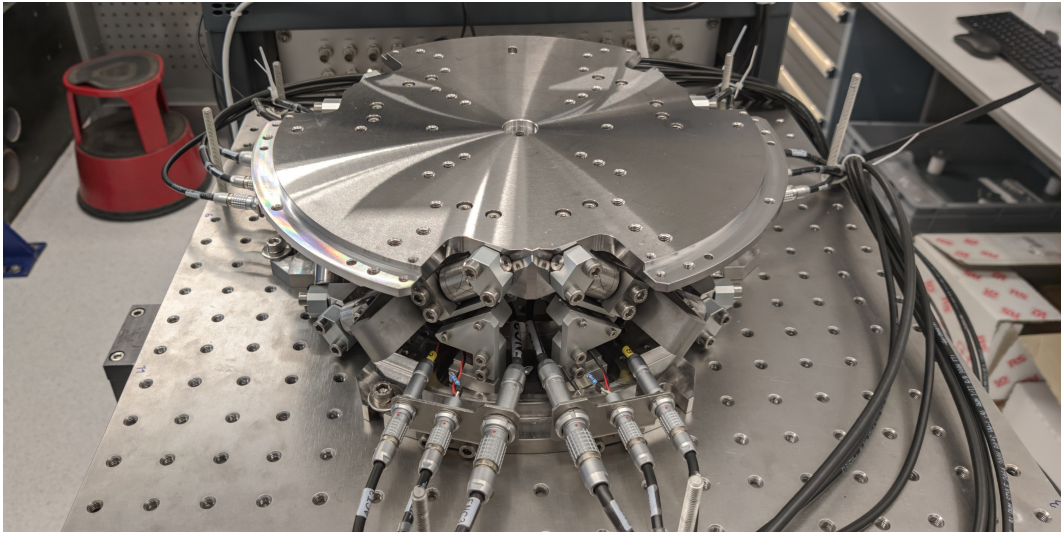
Strut - Extracted Model



Nano-Hexapod Mounting Tool



Mounted Nano-Hexapod



Nano-Hexapod - Identified Dynamics

Diagonal + off-diagonal transfer function from Va to De (comp with model)

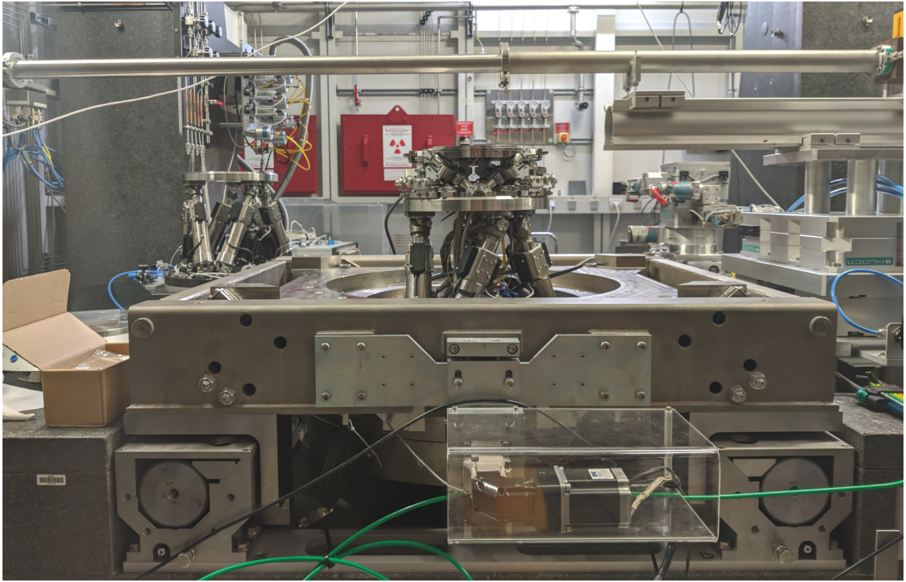
Nano-Hexapod - Force Sensors

Diagonal + off-diagonal transfer function from Va to Vs

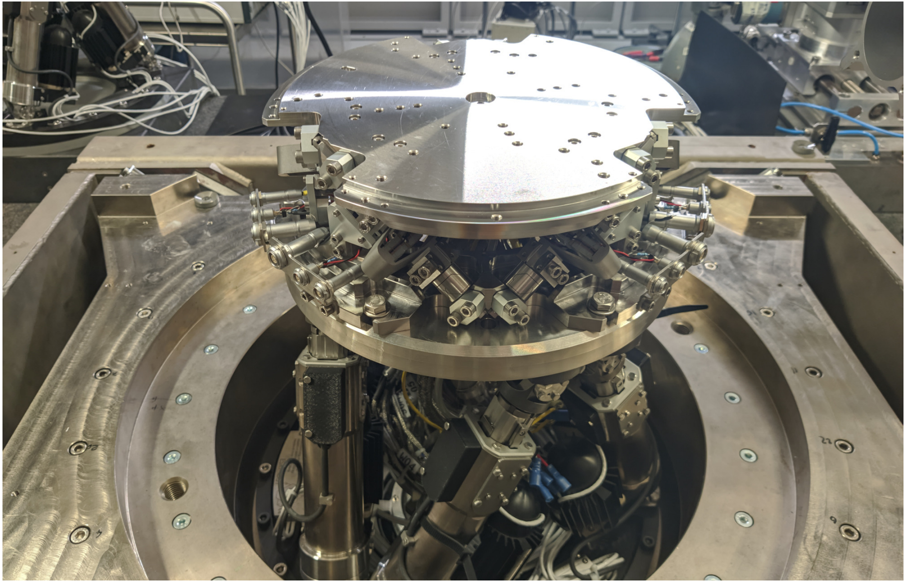
Nano-Hexapod - Damped Dynamics

Damped and Undamped, Diagonal + off-diagonal transfer function from Va to De

The Nano-Hexapod on top of the Micro-Station



The Nano-Hexapod on top of the Micro-Station



Conclusion