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

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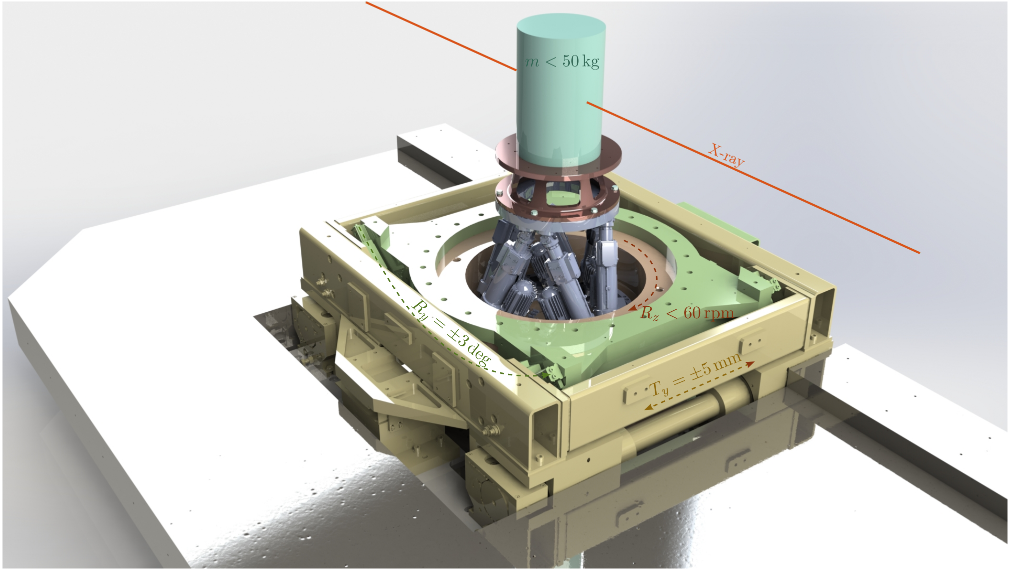
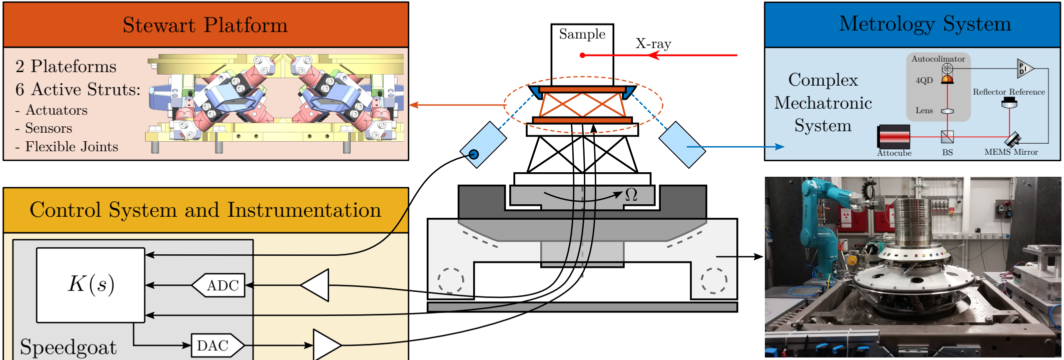
The ID31 Micro Station



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”



Stewart Platform

2 Plateforms
6 Active Struts:
- Actuators
- Sensors
- Flexible Joints

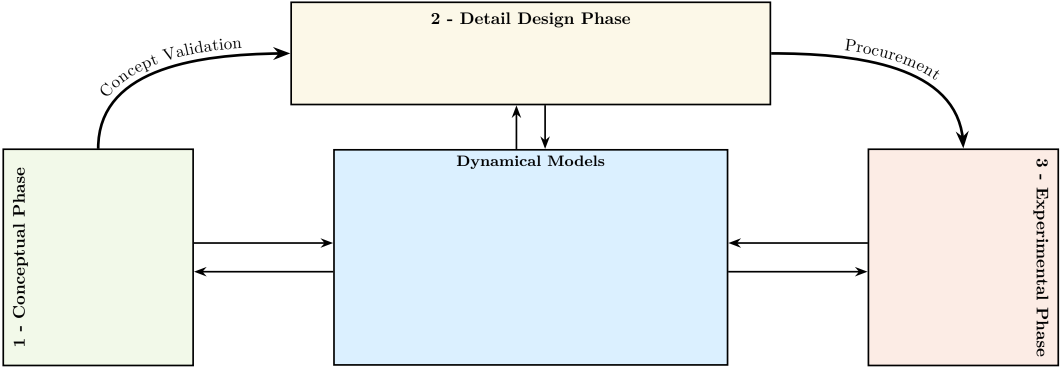
Metrology System

Complex Mechatronic System

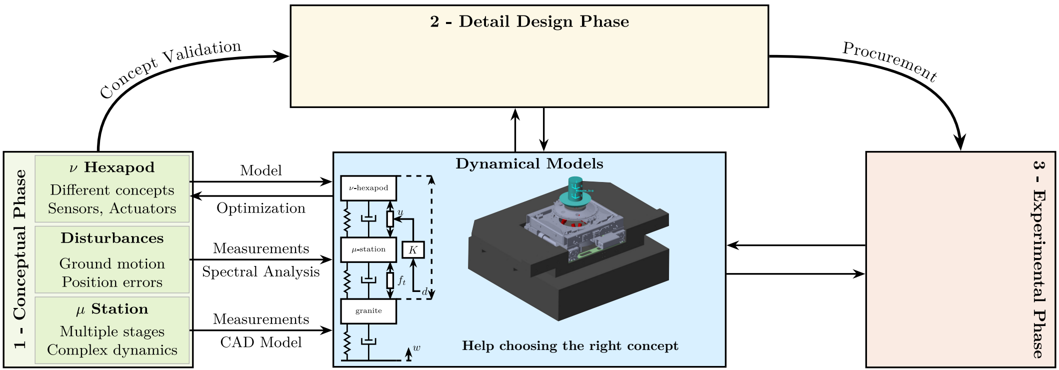
Control System and Instrumentation

ID31 Micro-Station

Overview of the Mechatronic Approach - Model Based Design



Outline - Conceptual Phase



1 - Conceptual Phase

ν Hexapod
Different concepts
Sensors, Actuators

Disturbances
Ground motion
Position errors

μ Station
Multiple stages
Complex dynamics

Model

Optimization

Measurements
Spectral Analysis

Measurements
CAD Model

Dynamical Models

Help choosing the right concept

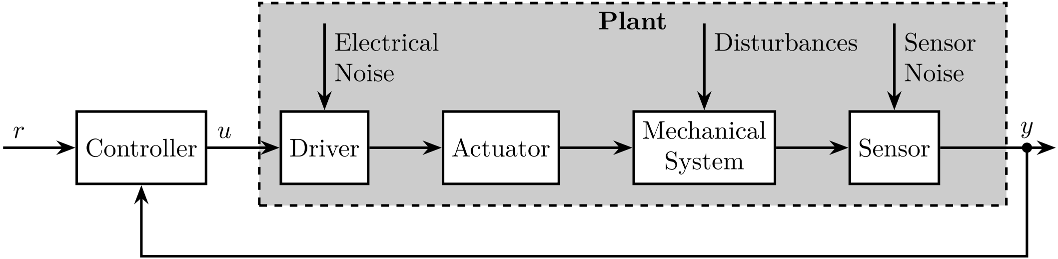
Concept Validation

2 - Detail Design Phase

Procurement

3 - Experimental Phase

Feedback Control - The Control Loop



Why Feedback?

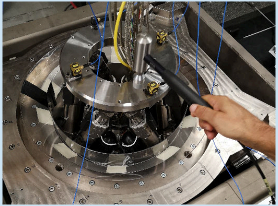
- Model uncertainties
- Unknown disturbances

Every elements can limit the performances

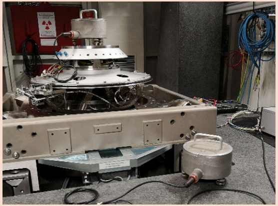
- Drivers, Actuators, Sensors
- Mechanical System
- Controller

Noise Budgeting and Required Control Bandwidth

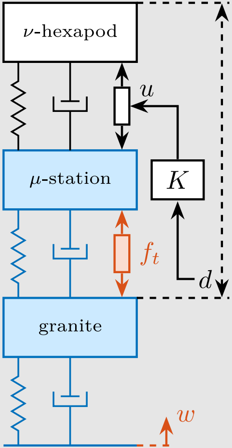
Dynamical Identification



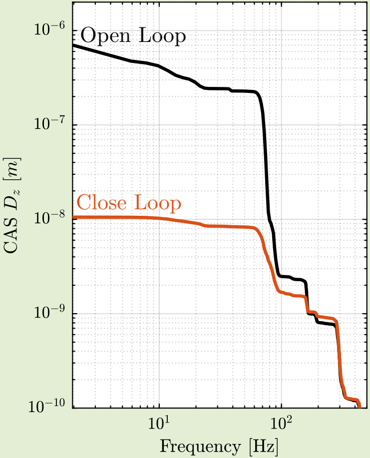
Disturbance Measurements



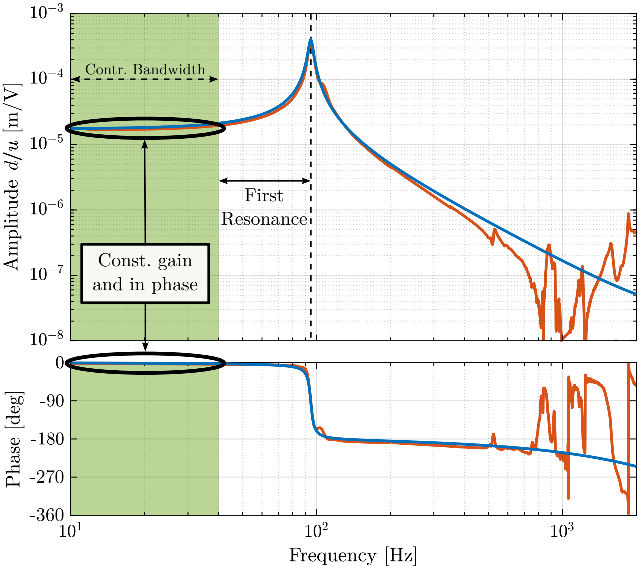
Mass-Spring-Damper Model

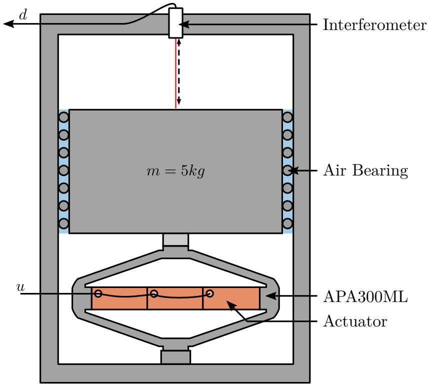


Noise Budgeting



Limitation of the Controller Bandwidth?

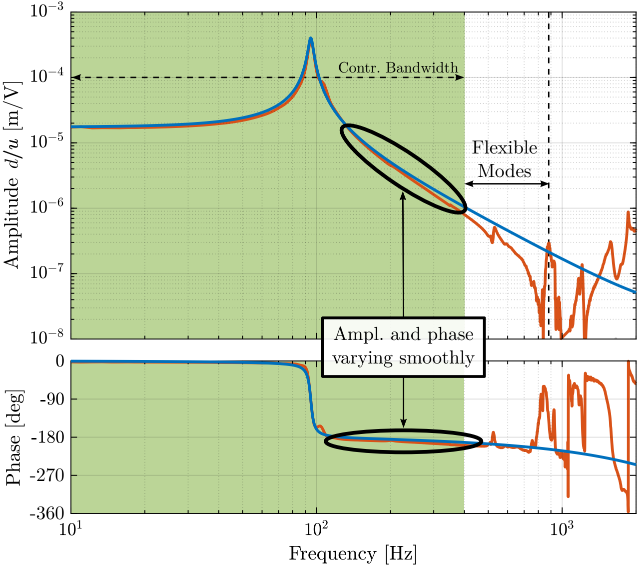


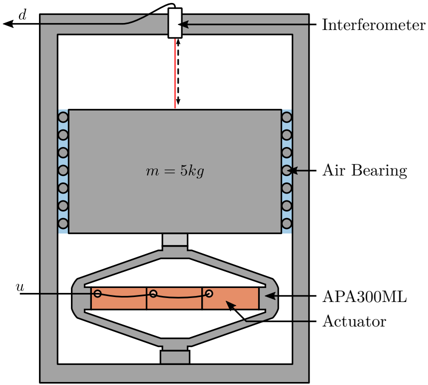


Typical Approach

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

Limitation of the Controller Bandwidth?

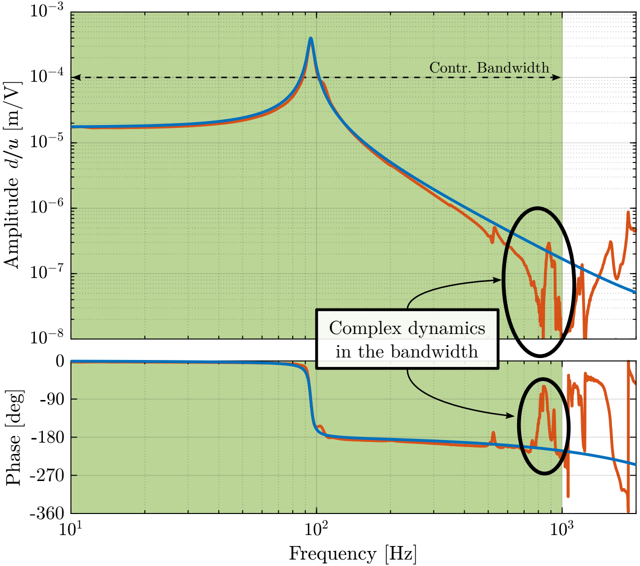


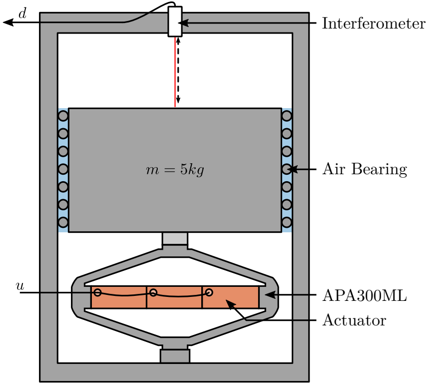


Alternative Approach

Limited by complex dynamics
Model based controller

Limitation of the Controller Bandwidth?

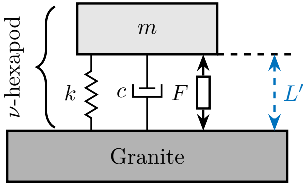


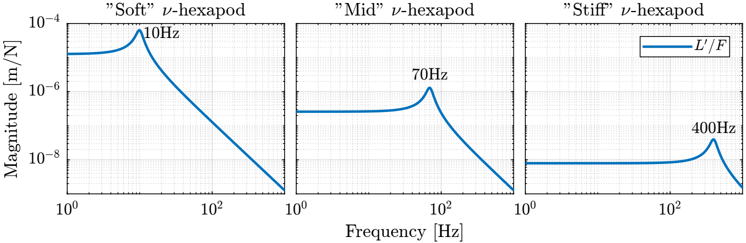


Next-Gen Systems

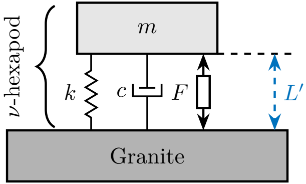
Active research topic
Complex controllers

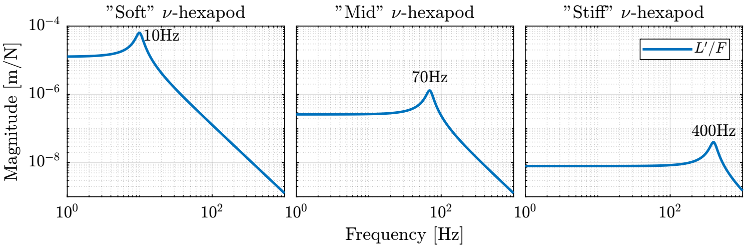
Soft or Stiff ν-hexapod ? Interaction with the μ-station

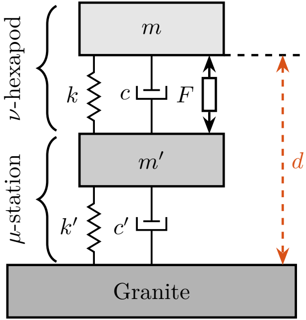


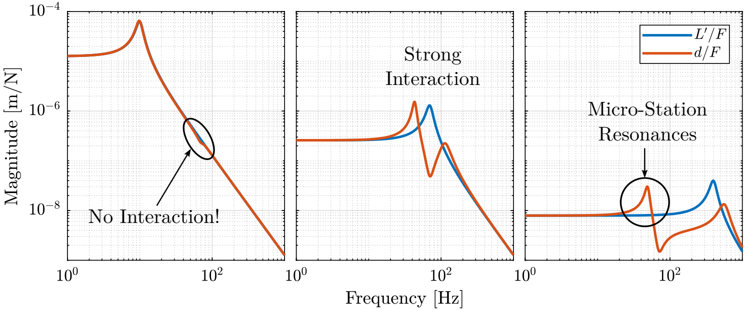


Soft or Stiff ν-hexapod ? Interaction with the μ-station

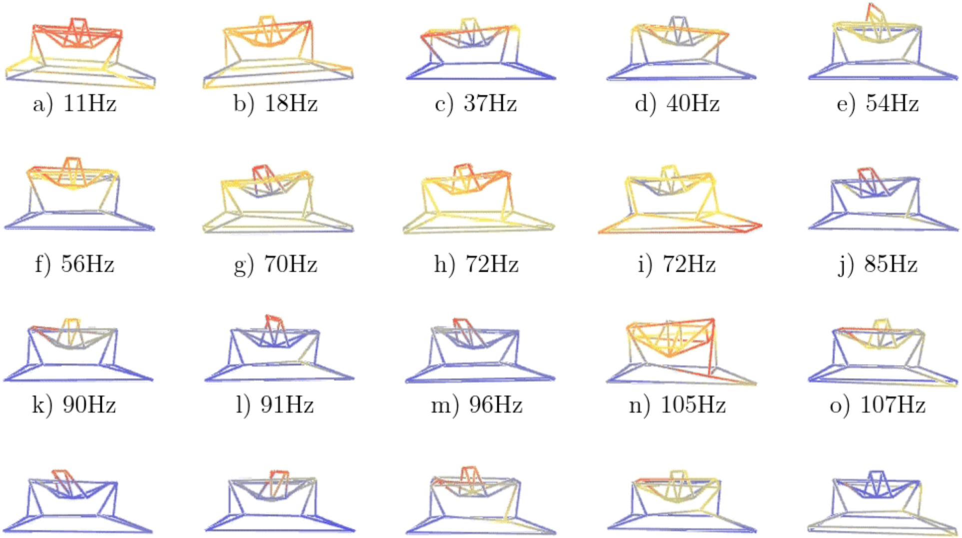






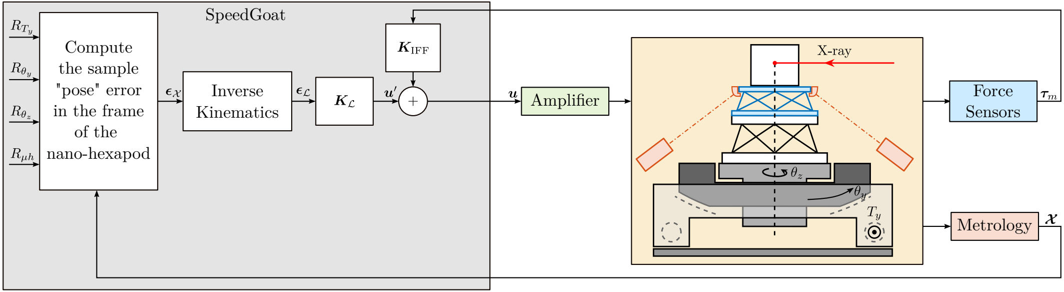


Complexity of the Micro-Station Dynamics (Model Analysis)



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



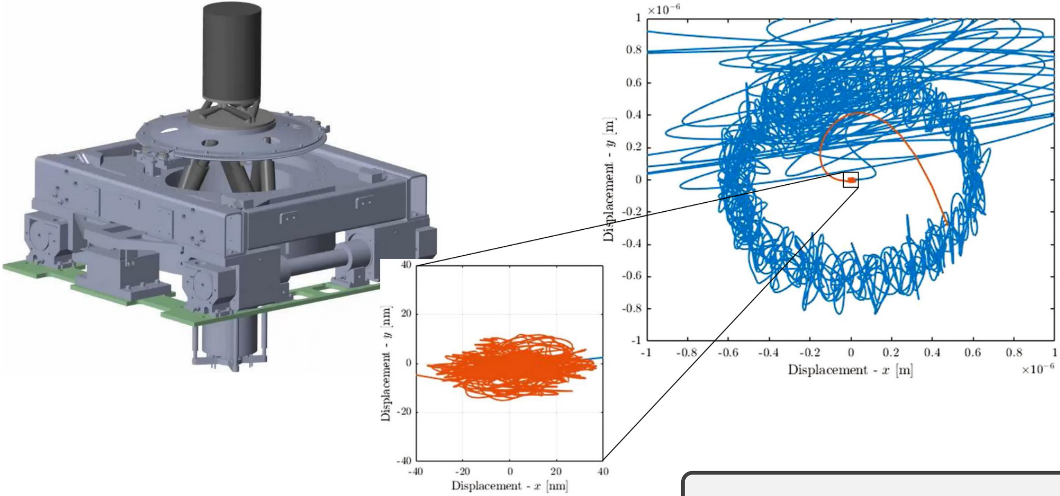
Low Authority Control

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

High Authority Control

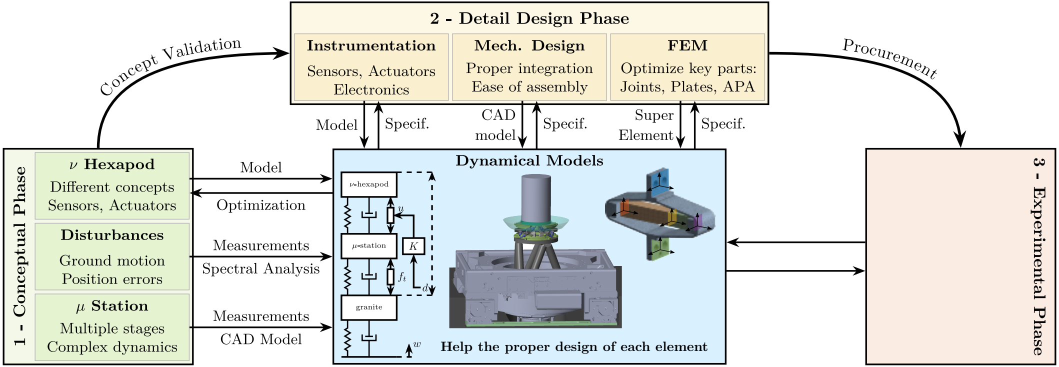
- Position sensors
- Complex dynamics
- ↘ vibration in the bandwidth
- Use transformation matrices

Multi-Body Models - Simulations



Validation of the concept

Outline - Detail Design Phase



2 - Detail Design Phase

Instrumentation
Sensors, Actuators
Electronics

Mech. Design
Proper integration
Ease of assembly

FEM
Optimize key parts:
Joints, Plates, APA

Concept Validation

Procurement

Model
Specif.
CAD model
Specif.
Super Element
Specif.

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Optimization
Measurements
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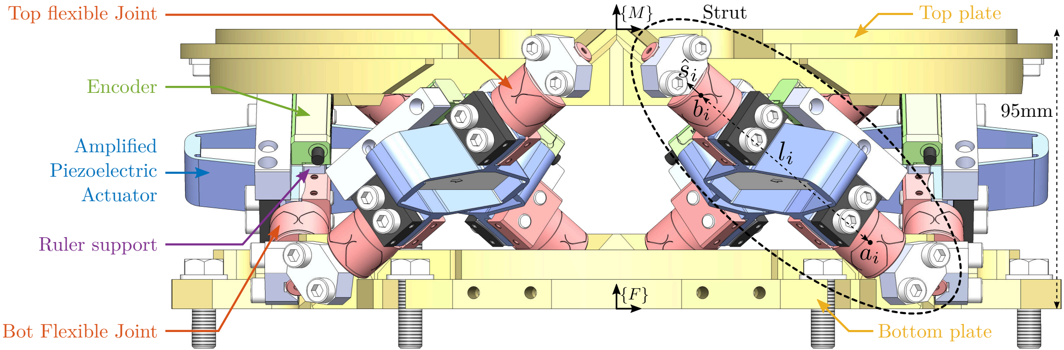
Dynamical Models

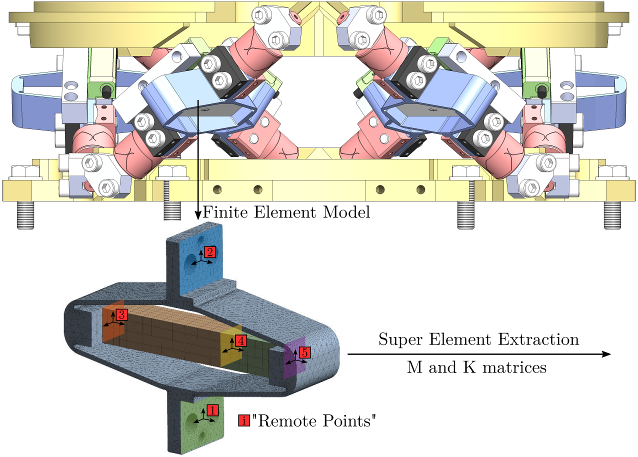
Help the proper design of each element

3 - Experimental Phase

Nano-Hexapod Overview - Key elements



Include Flexible Elements in a Multi-Body model

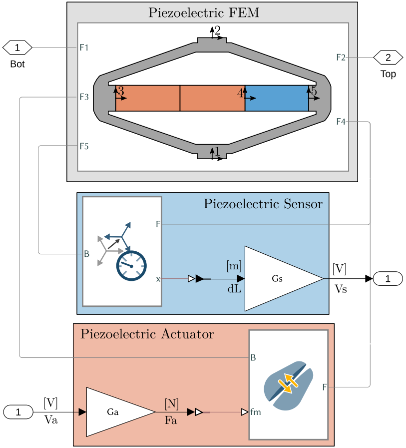


Finite Element Model

Super Element Extraction

M and K matrices

i "Remote Points"



Choice of Actuator - Amplifier Piezoelectric Actuator

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

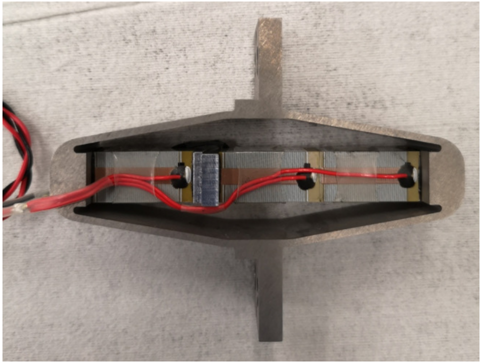


Fig.: Picture of the APA300ML

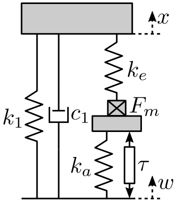


Fig.: 2-DoF Model

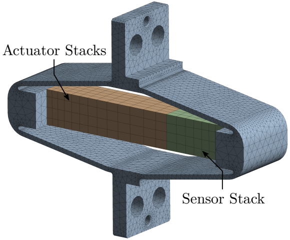


Fig.: APA Finite Element Model

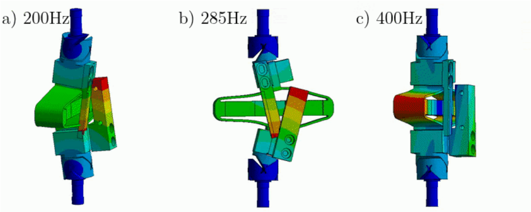


Fig.: Flexible Modes due to limited APA stiffness

Flexible Joints - Specifications and Optimization

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

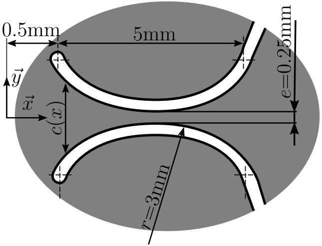


Fig.: Opt. geometry

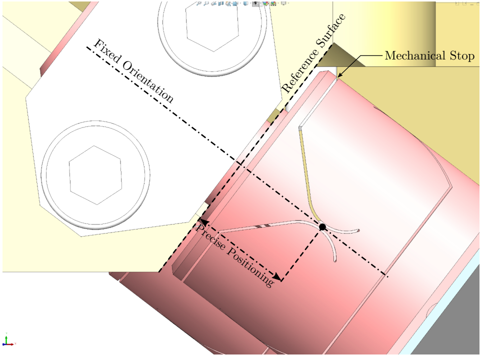


Fig.: Positioning of the top joint

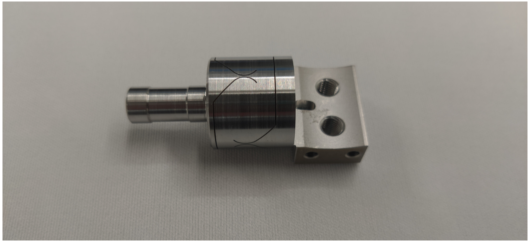


Fig.: Picture of the joint

Instrumentation

Fig.: PiezoDrive - PD200 Amplifier

Fig.: Renishaw - Vionic Encoder

Fig.: Speedgoat - Target Machine

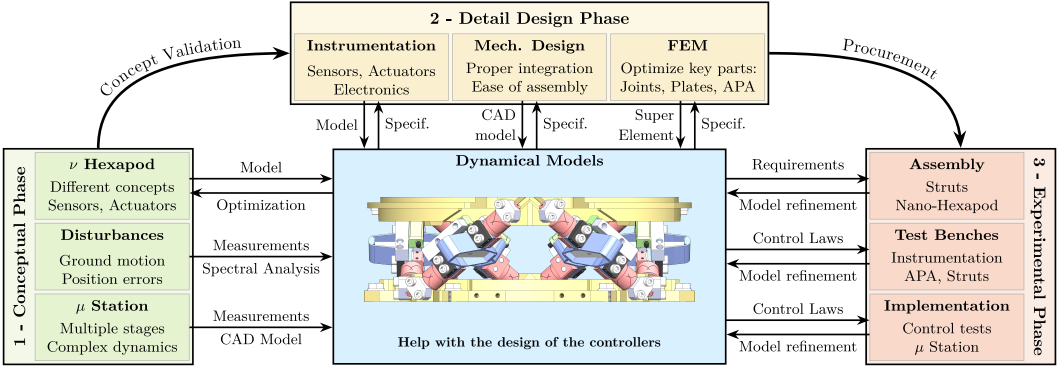
Characteristics	**Manual**
Gain	20
Noise	0.7 mV rms
Small Signal BW	7.4 kHz
Large Signal BW	300 Hz

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



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1 - Conceptual Phase

***ν* Hexapod**
Different concepts
Sensors, Actuators

Disturbances
Ground motion
Position errors

***μ* Station**
Multiple stages
Complex dynamics

Model
Optimization
Measurements
Spectral Analysis
Measurements
CAD Model

Dynamical Models

Help with the design of the controllers

Requirements
Model refinement
Control Laws
Model refinement
Control Laws
Model refinement

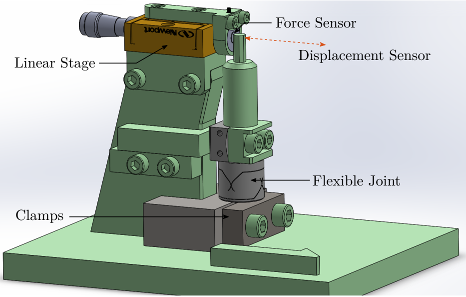
3 - Experimental Phase

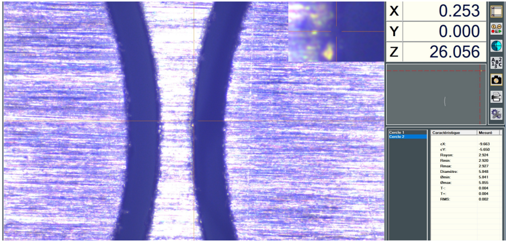
Assembly
Struts
Nano-Hexapod

Test Benches
Instrumentation
APA, Struts

Implementation
Control tests
μ Station

Flexible Joints - Measurements

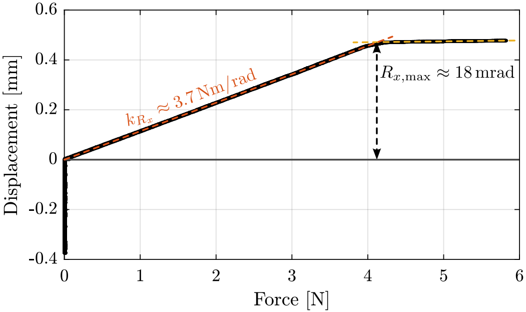




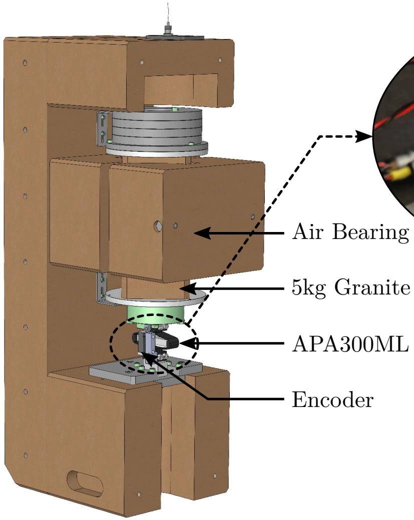
X	0.253
Y	0.000
Z	26.056

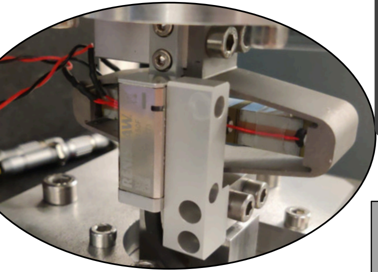
Cercle 1
Cercle 2

Caractéristique	Mesuré
cX:	-9.663
cY:	-5.650
Rayon:	2.924
Rmin:	2.920
Rmax:	2.927
Diamètre:	5.848
Ømin:	5.841
Ømax:	5.855
T-:	0.004
T+:	0.004
RMS:	0.002



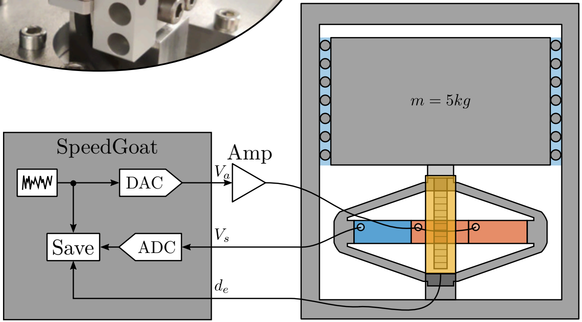
Amplified Piezoelectric Actuator - Test Bench



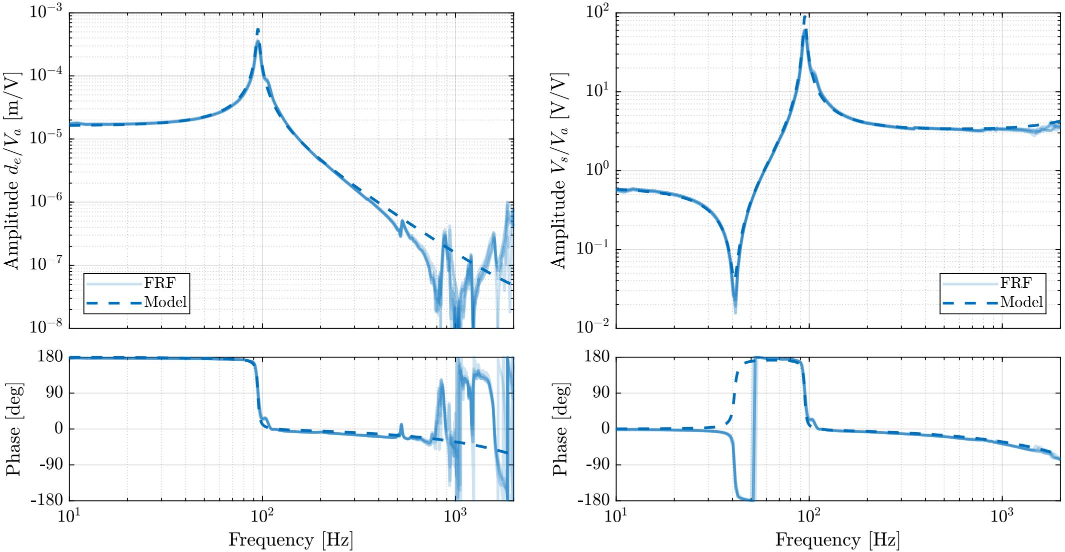


Goals

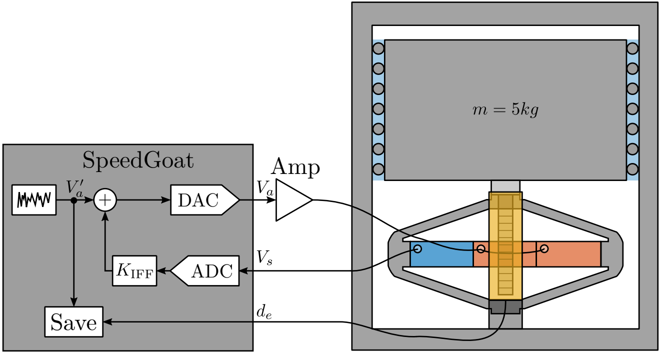
- Identify Dynamics
- Tune APA Model
- Test IFF



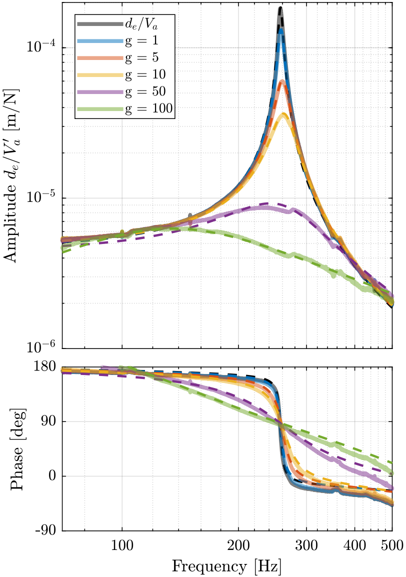
Amplified Piezoelectric Actuator - Extracted Model



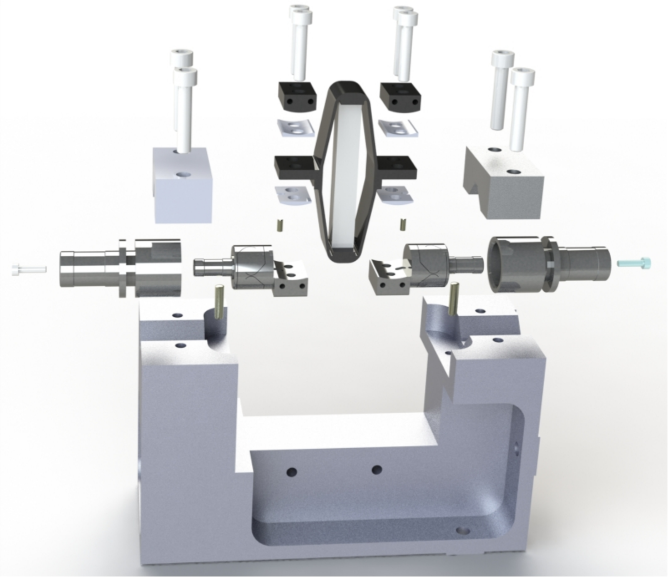
Amplified Piezoelectric Actuator - Integral Force Feedback

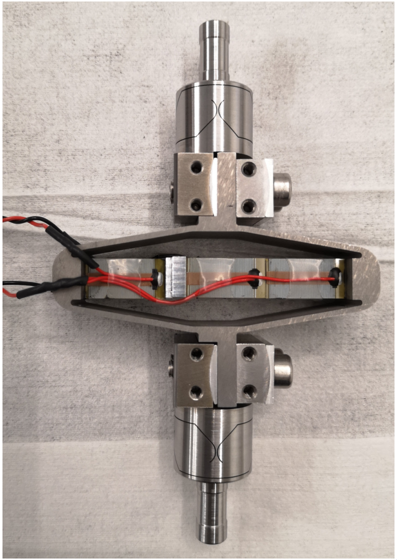


$$K_{\mathsf{IFF}}(s) = \frac{g}{s}$$

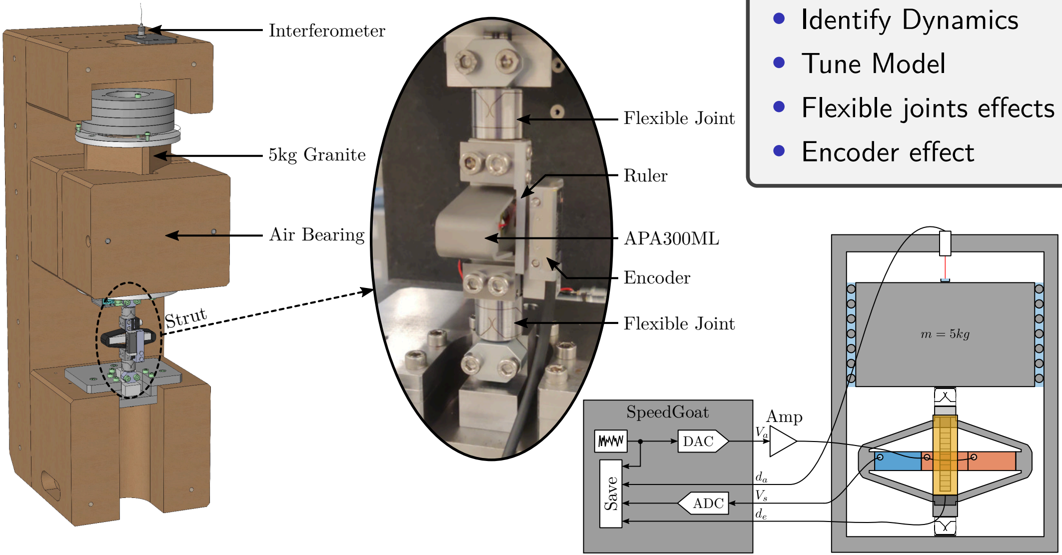


Strut - Mounting Tool





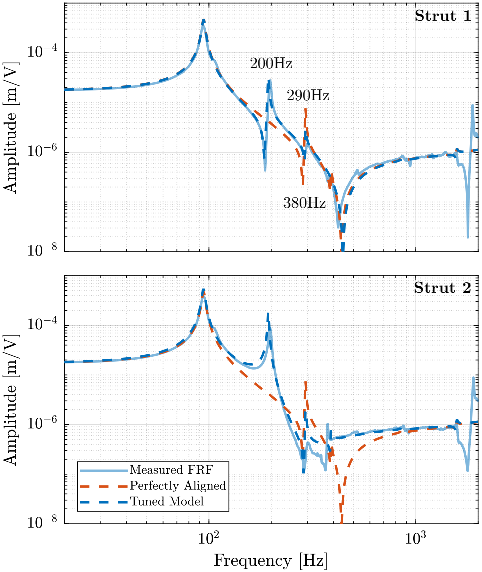
Strut - Dynamical Measurements

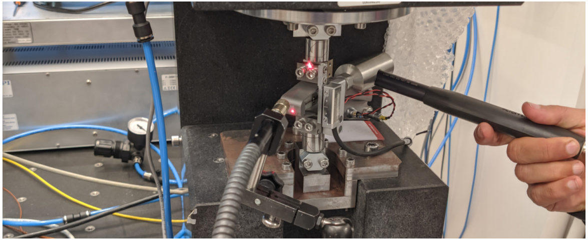


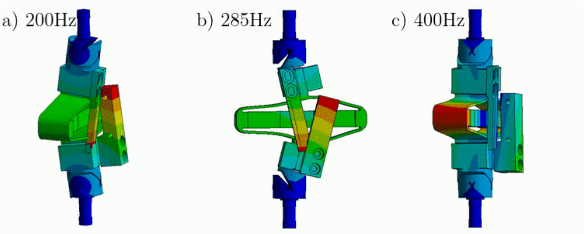
Goals

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

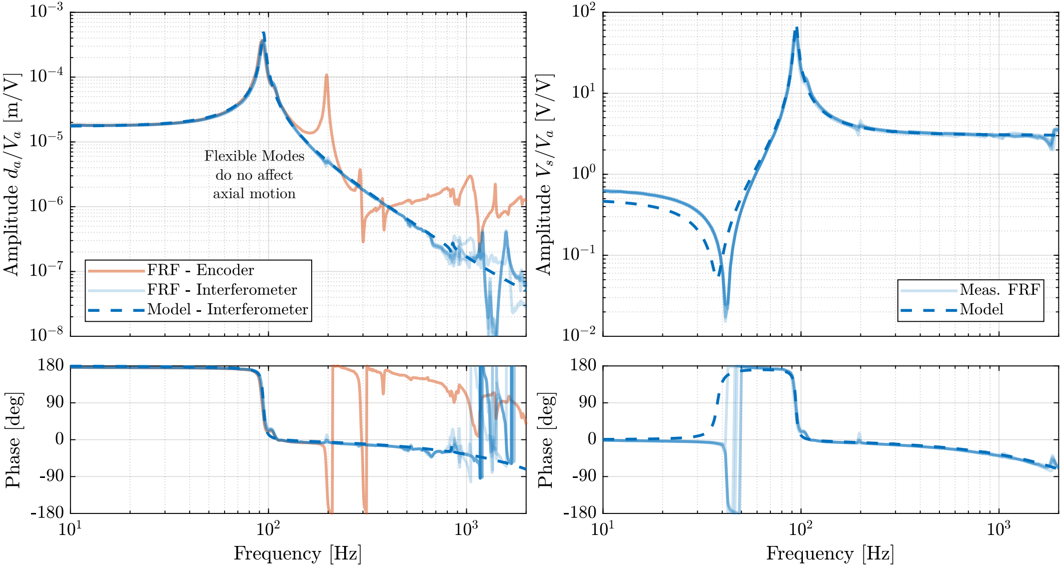
Strut - Encoders Output and Spurious Modes



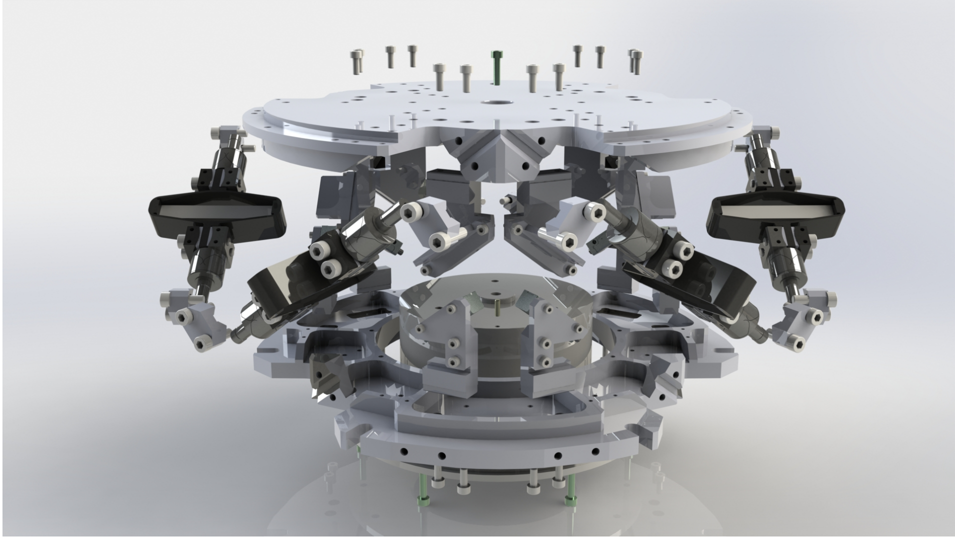




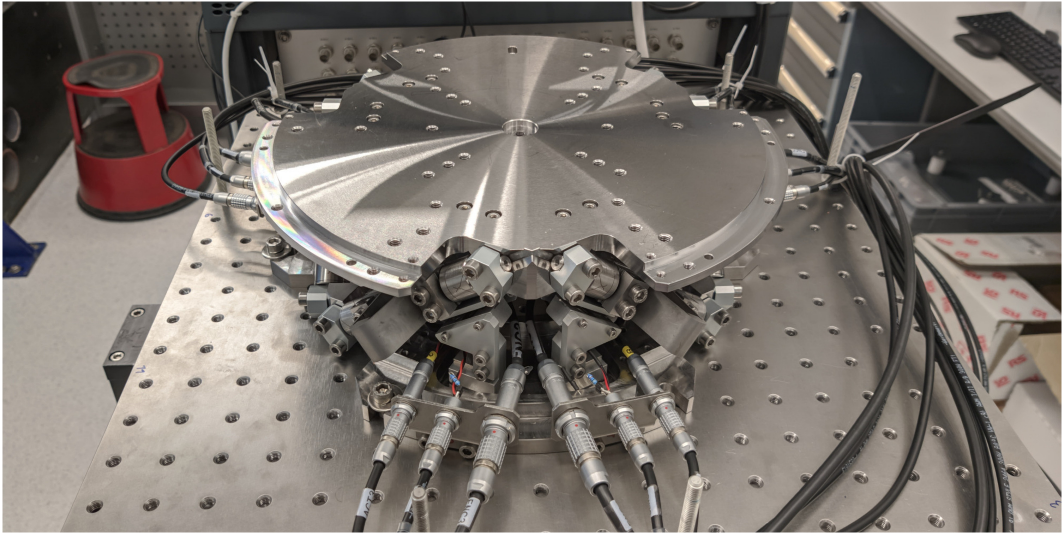
Strut - Extracted Model



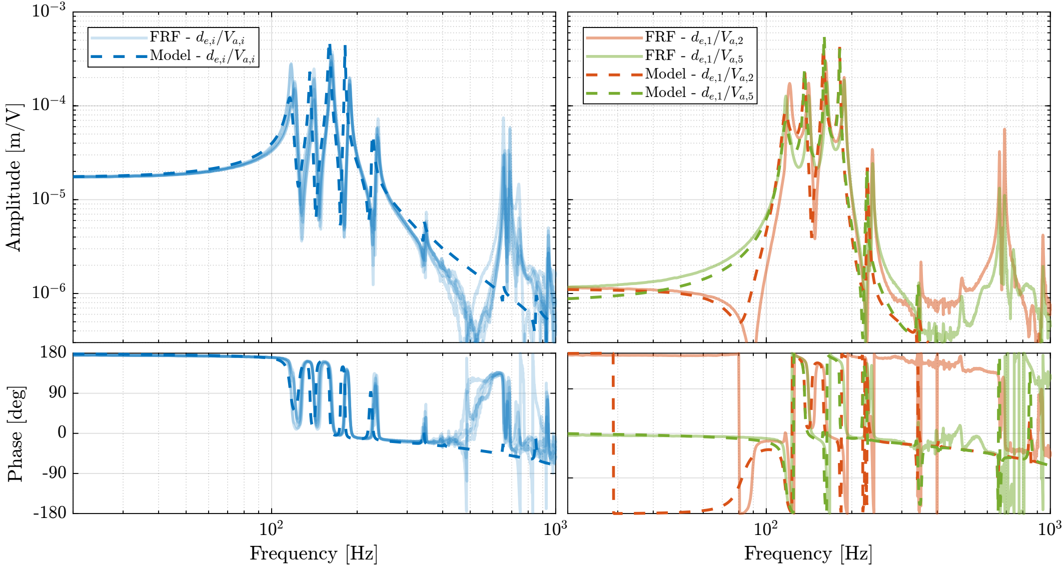
Nano-Hexapod Mounting Tool



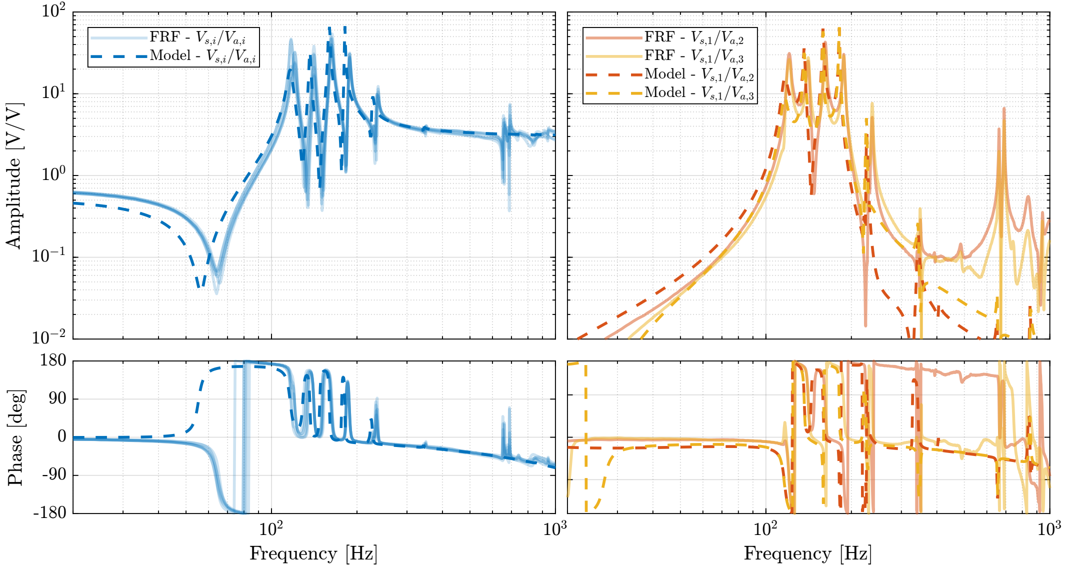
Mounted Nano-Hexapod



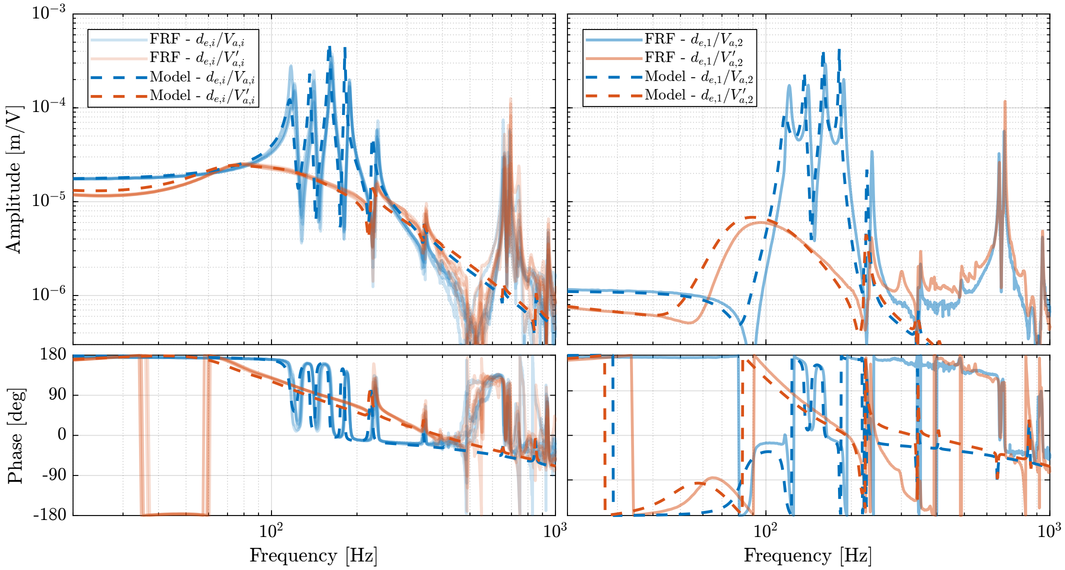
Nano-Hexapod - Identified Dynamics



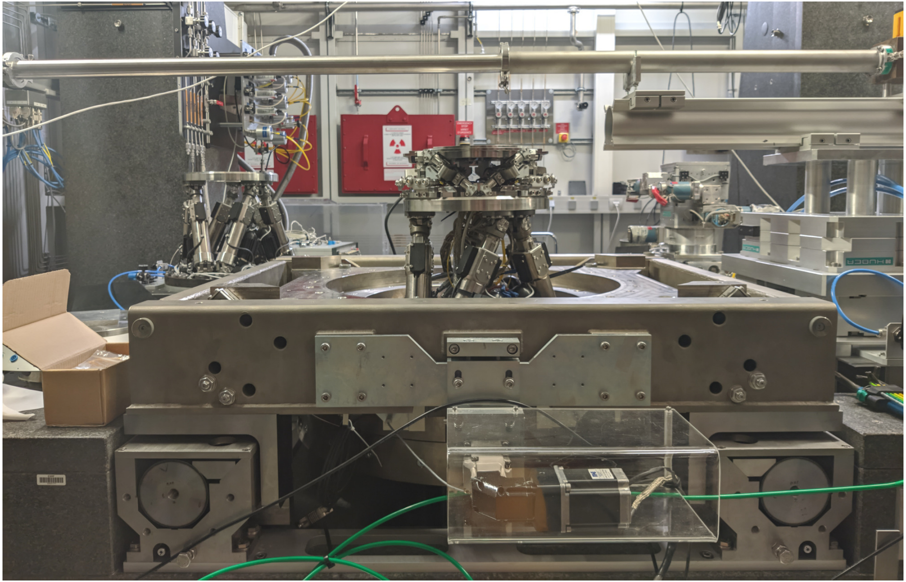
Nano-Hexapod - Force Sensors



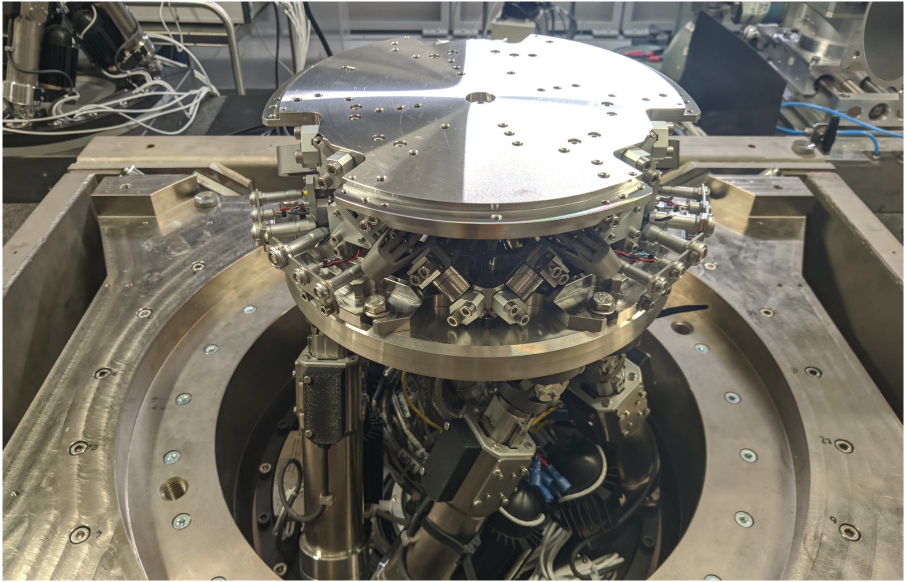
Nano-Hexapod - Damped Dynamics



The Nano-Hexapod on top of the Micro-Station



The Nano-Hexapod on top of the Micro-Station



Conclusion