

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

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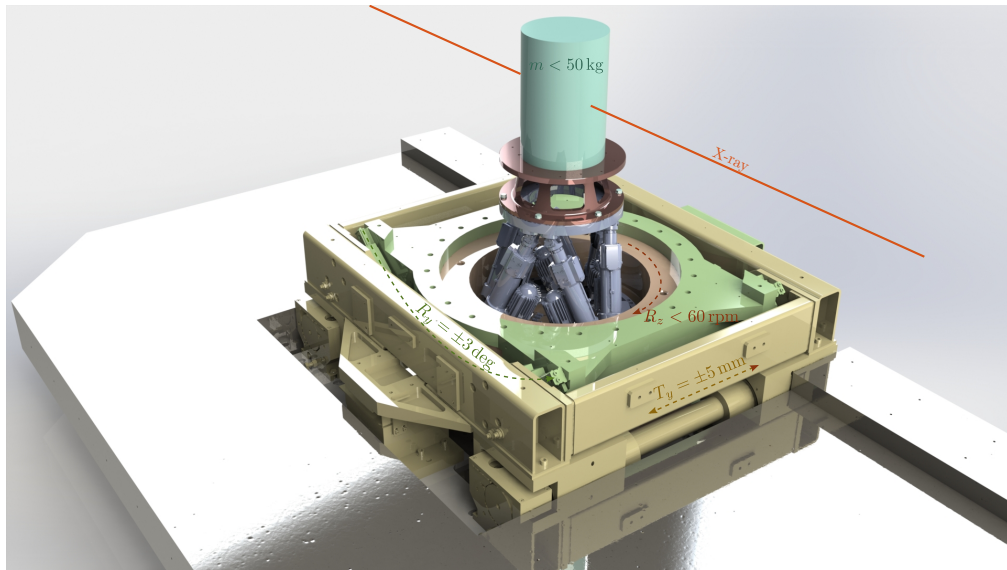
³BEAMS Department, Free University of Brussels, Belgium



**Precision
Mechatronics
Laboratory**



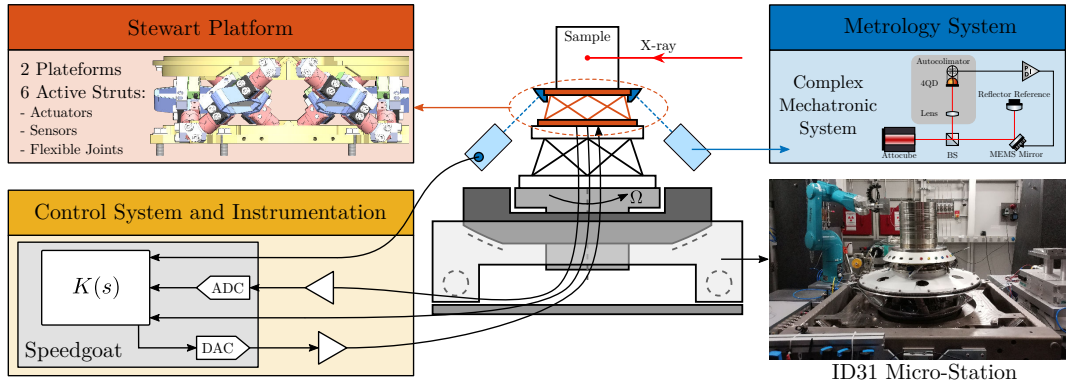
The ID31 Micro Station



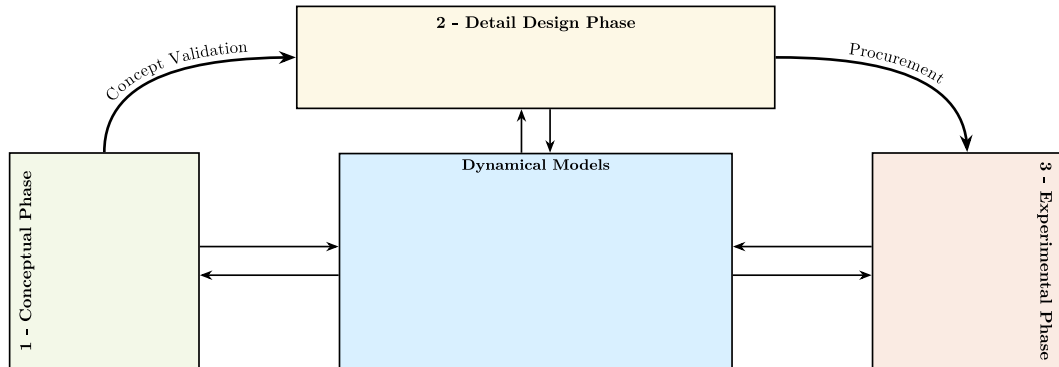
Introduction - The Nano Active Stabilization System (NASS)

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

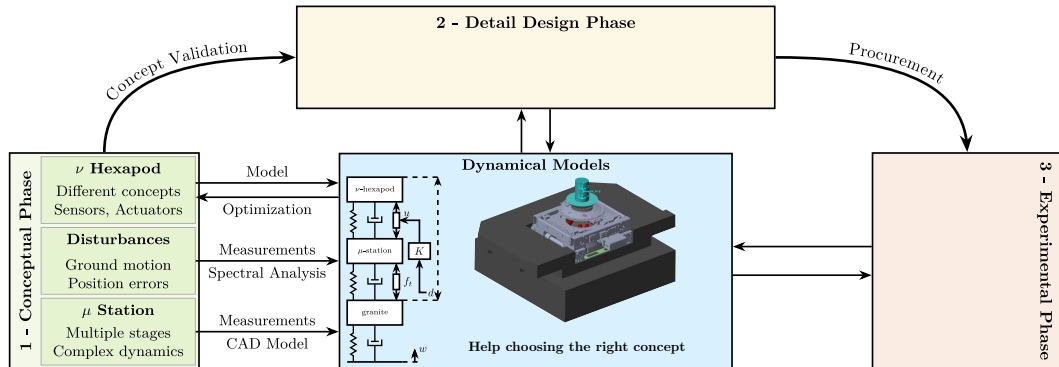
Design approach: “Model based design” / “Predictive Design”



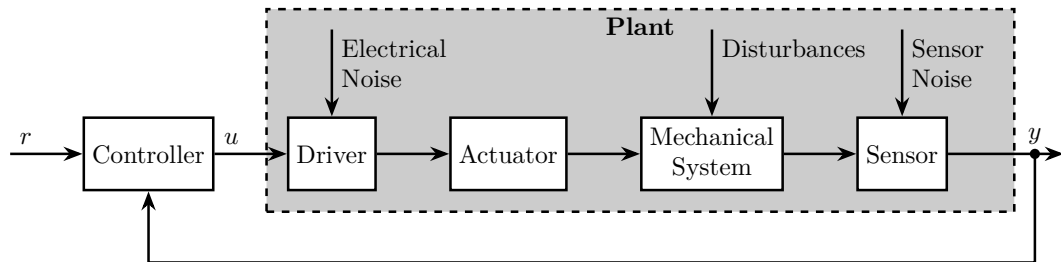
Overview of the Mechatronic Approach - Model Based Design



Outline - Conceptual Phase



Feedback Control - The Control Loop



Why Feedback?

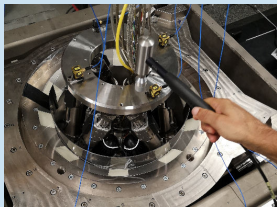
- Model uncertainties
- Unknown disturbances

Every elements can limit the performances

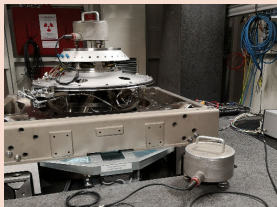
- Drivers, Actuators, Sensors
- Mechanical System
- Controller

Noise Budgeting and Required Control Bandwidth

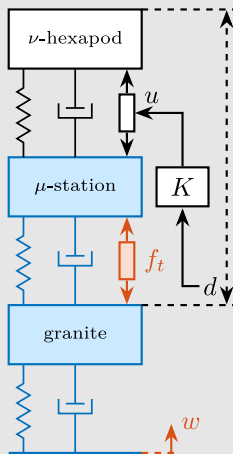
Dynamical Identification



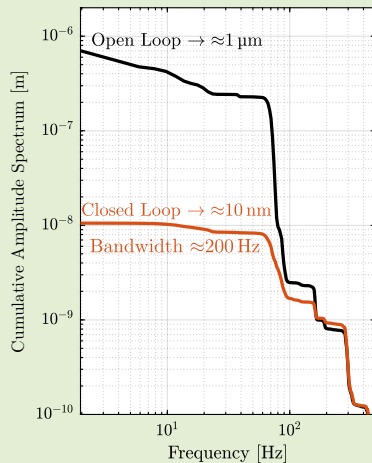
Disturbance Measurements



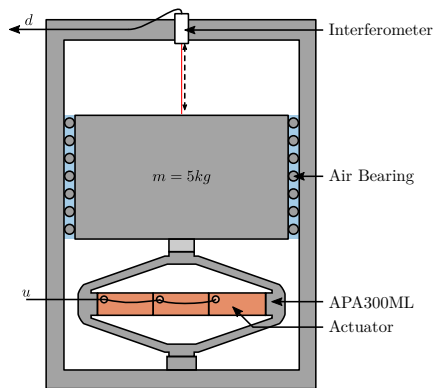
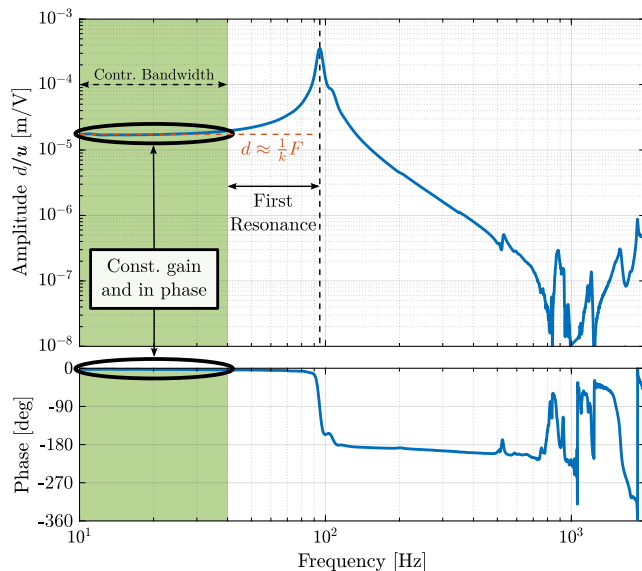
Mass-Spring-Damper Model



Noise Budgeting



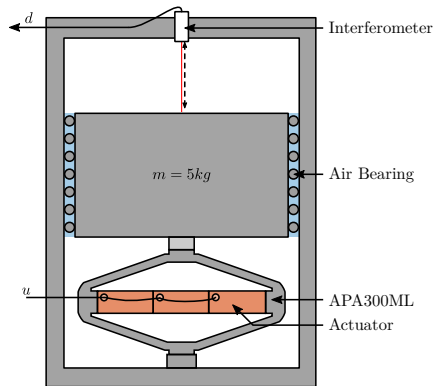
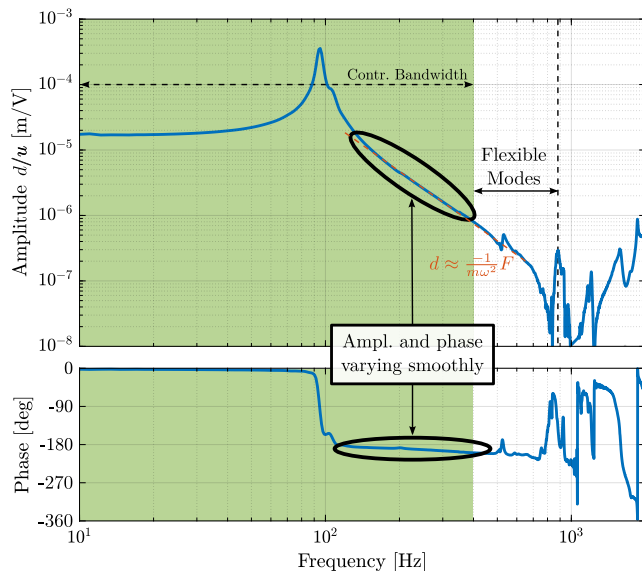
Limitation of the Controller Bandwidth?



Typical Approach

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

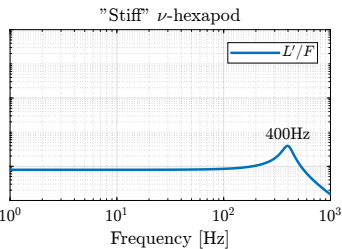
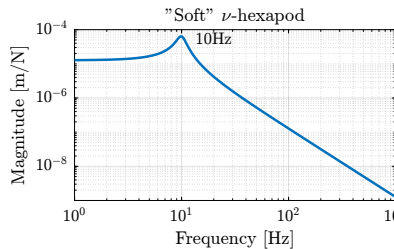
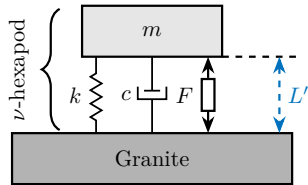
Limitation of the Controller Bandwidth?



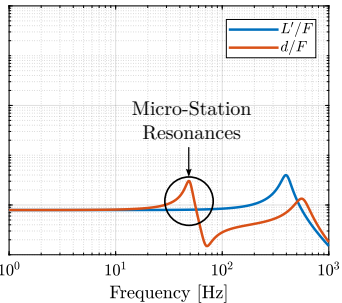
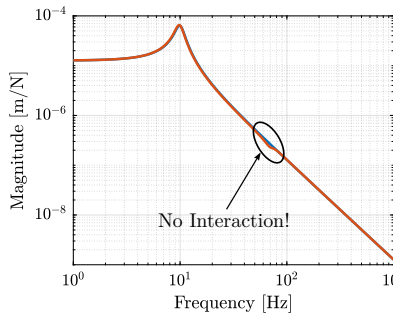
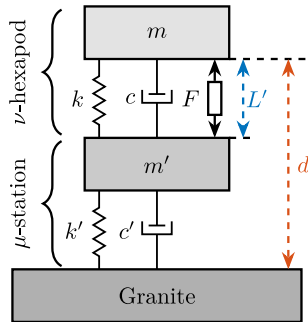
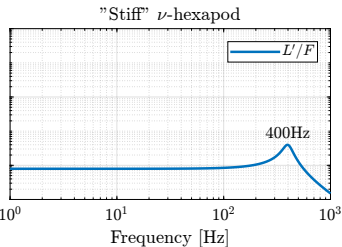
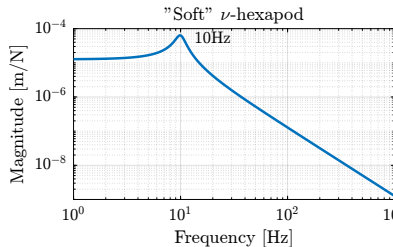
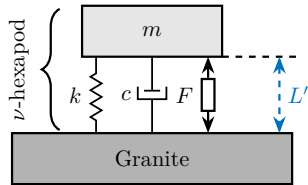
Alternative Approach

Limited by complex dynamics
Model based controller

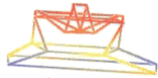
Soft or Stiff ν -hexapod ? Interaction with the μ -station



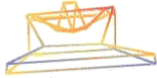
Soft or Stiff ν -hexapod ? Interaction with the μ -station



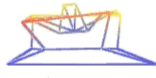
Complexity of the Micro-Station Dynamics (Model Analysis)



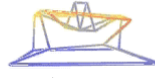
a) 11Hz



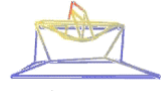
b) 18Hz



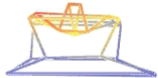
c) 37Hz



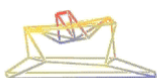
d) 40Hz



e) 54Hz



f) 56Hz



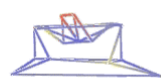
g) 70Hz



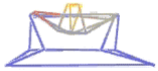
h) 72Hz



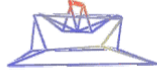
i) 72Hz



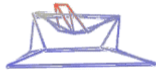
j) 85Hz



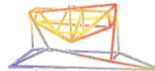
k) 90Hz



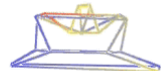
l) 91Hz



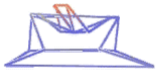
m) 96Hz



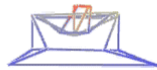
n) 105Hz



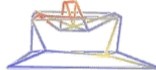
o) 107Hz



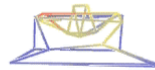
p) 113Hz



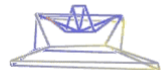
q) 117Hz



r) 124Hz

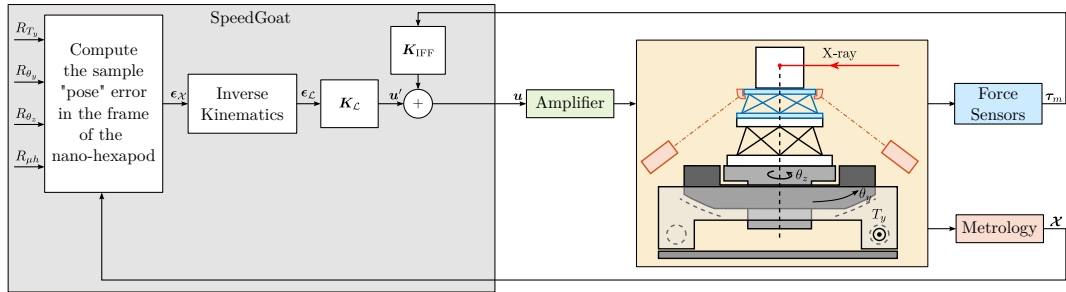


s) 145Hz



t) 150Hz

Control Strategy: HAC-LAC



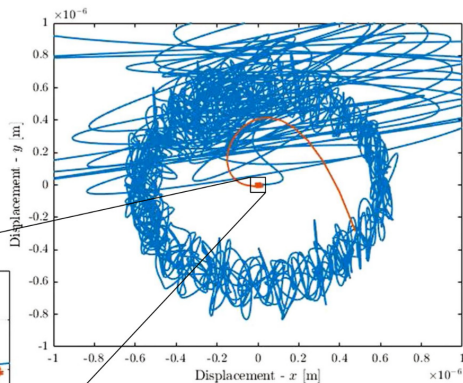
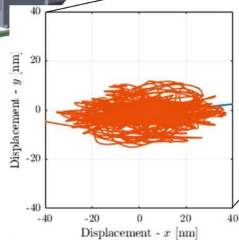
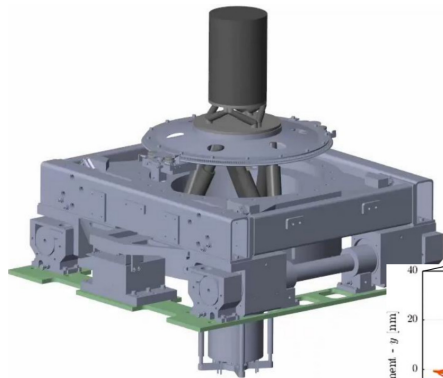
Low Authority Control

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

High Authority Control

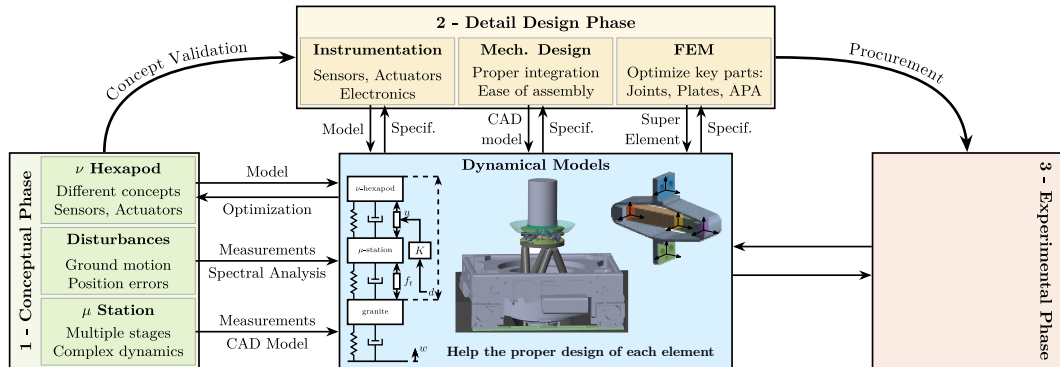
- Position sensors
- Complex dynamics
- Use transformation matrices
- ↘ vibration in the bandwidth

Multi-Body Models - Simulations

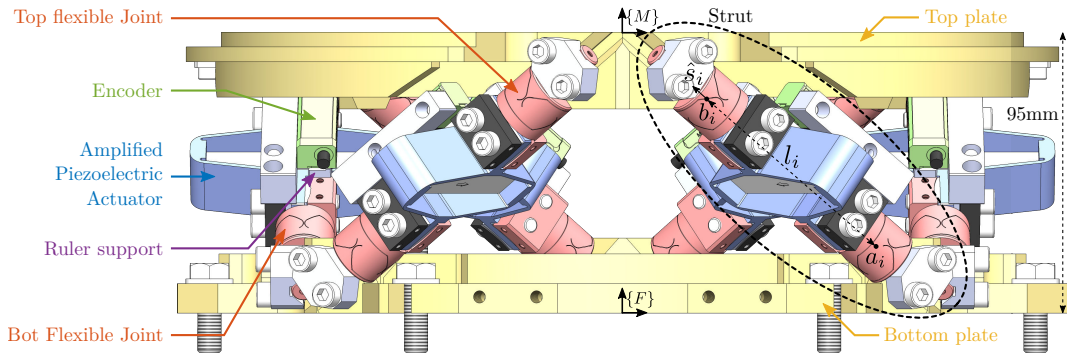


Validation of the concept

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.	$\approx 2 \text{ N}/\mu\text{m}$	$1.8 \text{ N}/\mu\text{m}$
Sufficient Stroke	$> 100 \mu\text{m}$	$368 \mu\text{m}$
Height	$< 50 \text{ mm}$	30 mm
High Resolution	$< 5 \text{ nm}$	3 nm

Characteristic	Specs	FEM
Axial Stiff.	$> 100 \text{ N}/\mu\text{m}$	94
Bending Stiff.	$< 100 \text{ Nm/rad}$	5
Torsion Stiff.	$< 500 \text{ Nm/rad}$	260
Bending Stroke	$> 1 \text{ mrad}$	20

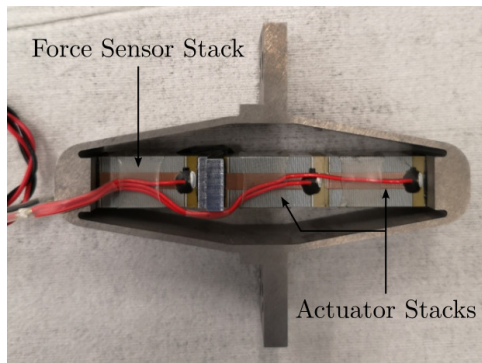


Fig.: Picture of the APA300ML



Fig.: Picture of the joint

Instrumentation



Fig.: PiezoDrive - PD200 Amplifier

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



Fig.: Renishaw - Vionic Encoder

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

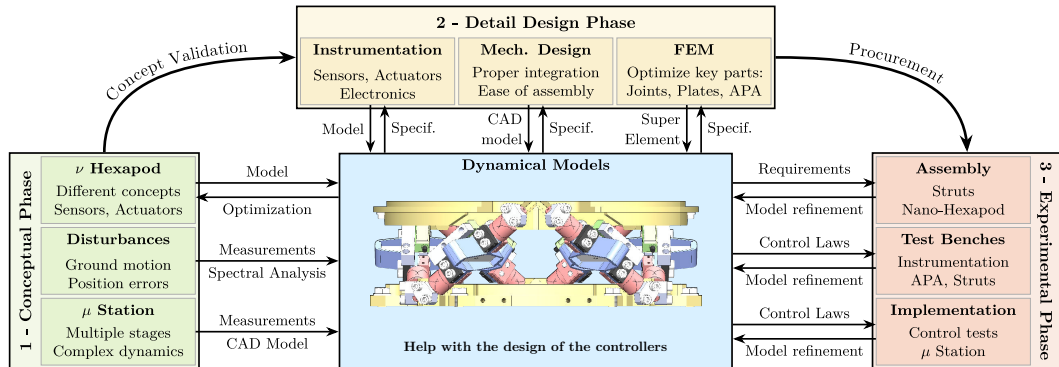


Fig.: Speedgoat - Target Machine

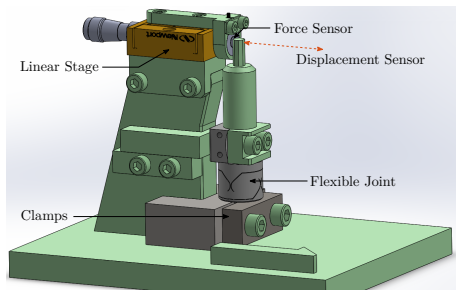
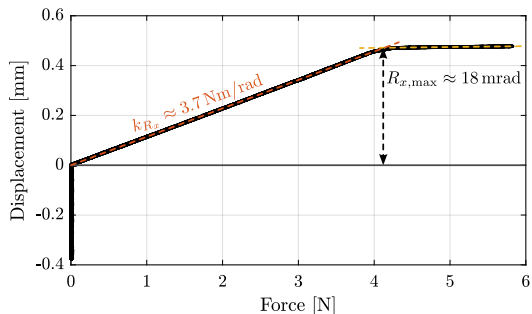
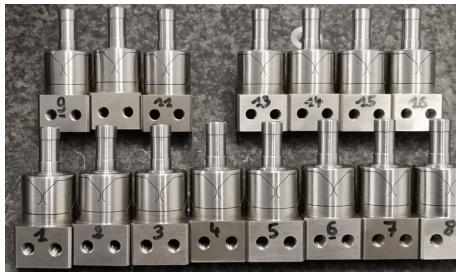
Characteristics	Manual
ADC (x16)	16bit, ± 10 V
DAC (x8)	16bit, ± 10 V
Digital I/O (x30)	$< \pm 15$ nm
Sampling Freq.	> 10 kHz

All elements could be chosen/design based on the models

Outline - Experimental Phase



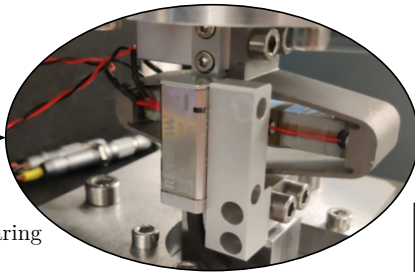
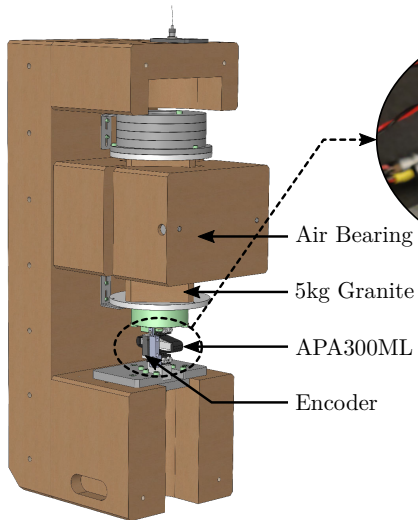
Flexible Joints - Measurements



Other Measurement Benches

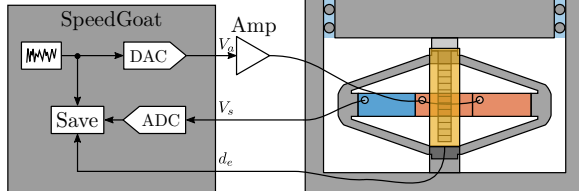
- Amplifier Output Noise and Bandwidth
- Encoder Measurement Noise
- DAC Output Noise

Amplified Piezoelectric Actuator - Test Bench

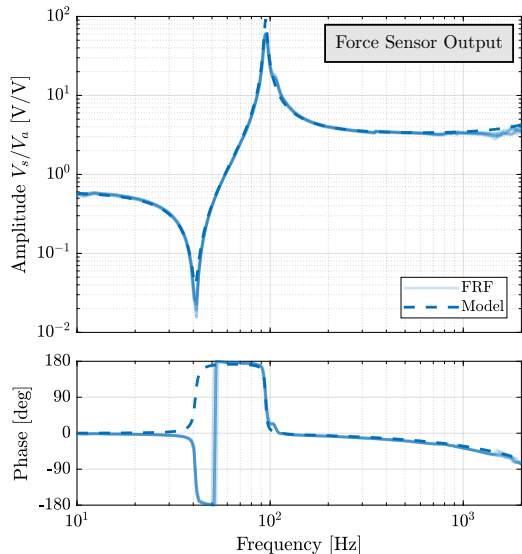
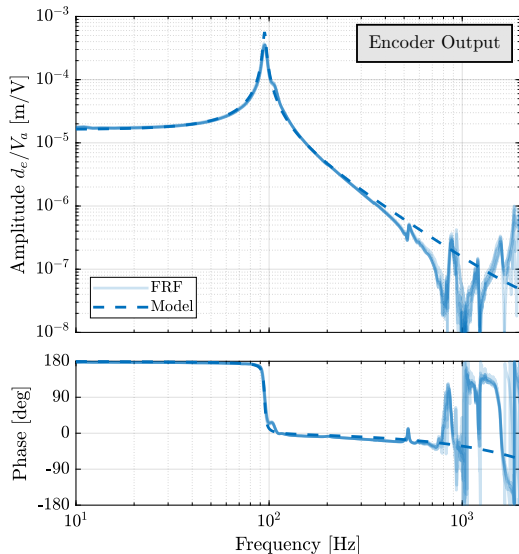


Goals

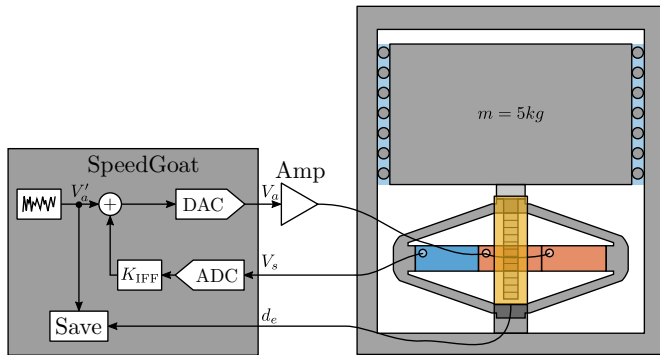
- Identify Dynamics
- Tune APA Model
- Test IFF



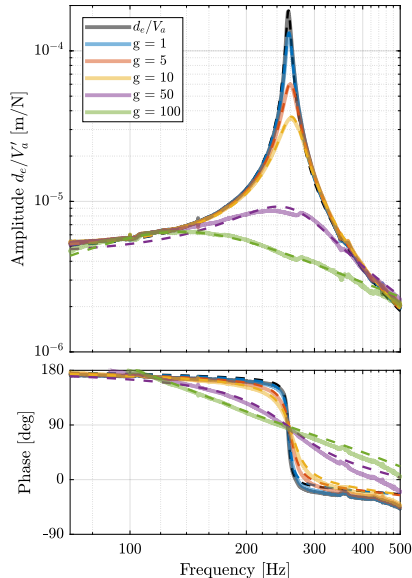
Amplified Piezoelectric Actuator - Measured FRF and Extracted Model



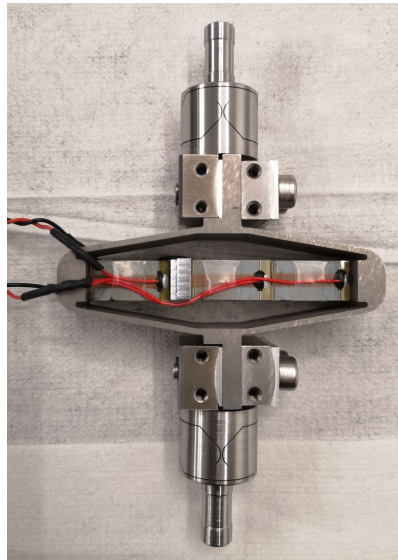
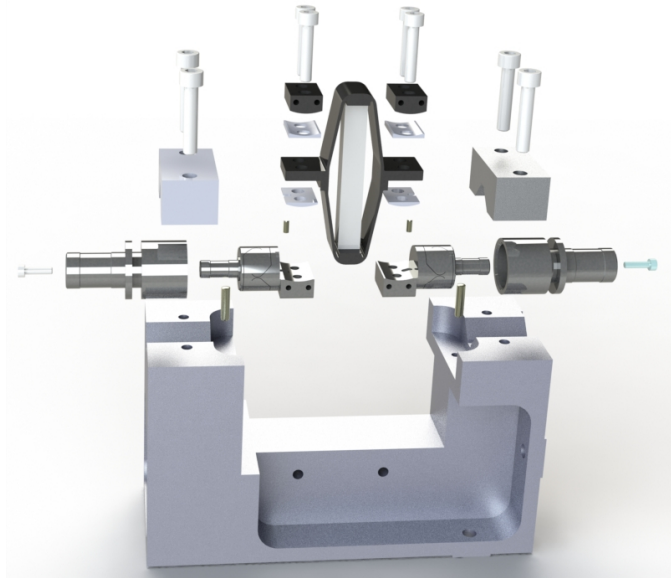
Amplified Piezoelectric Actuator - Integral Force Feedback



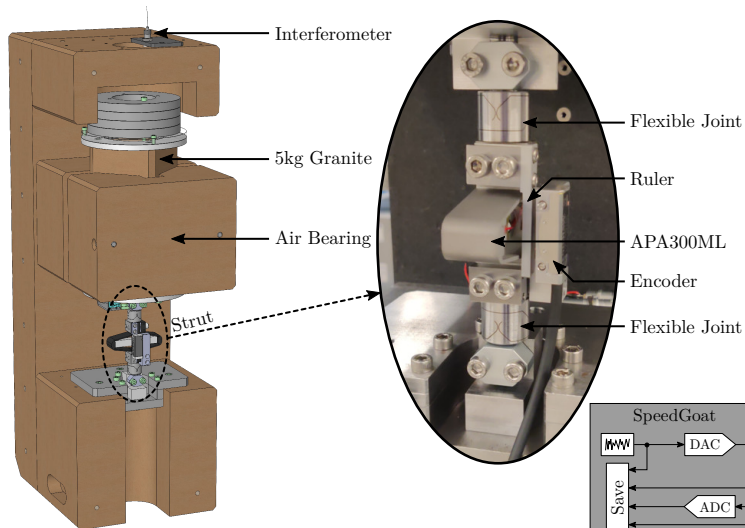
$$K_{IFF}(s) = \frac{g}{s}$$



Strut - Mounting Tool

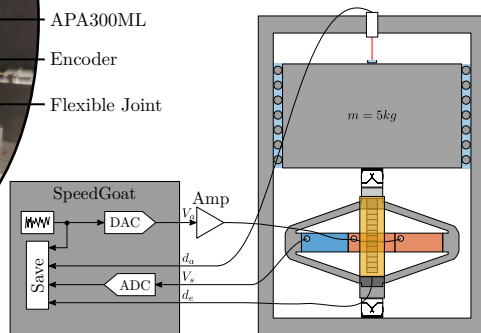


Strut - Dynamical Measurements

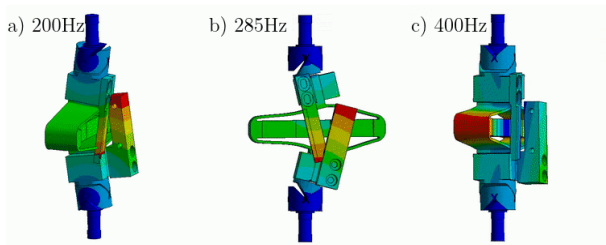
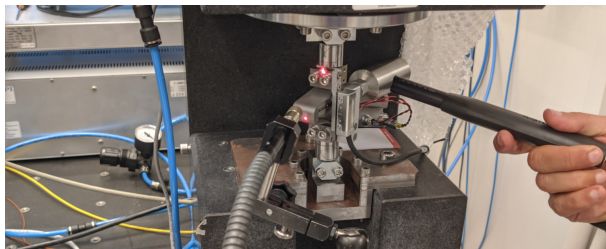
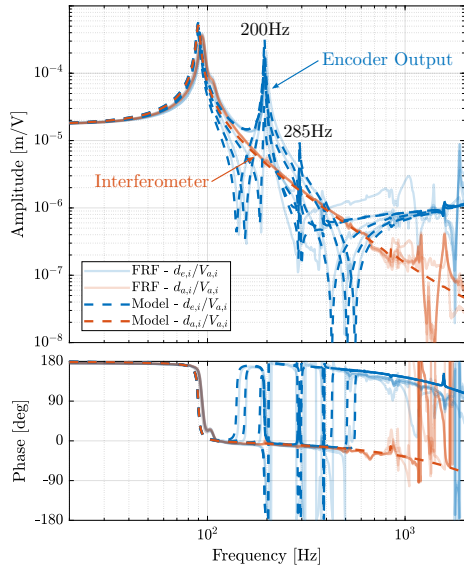


Goals

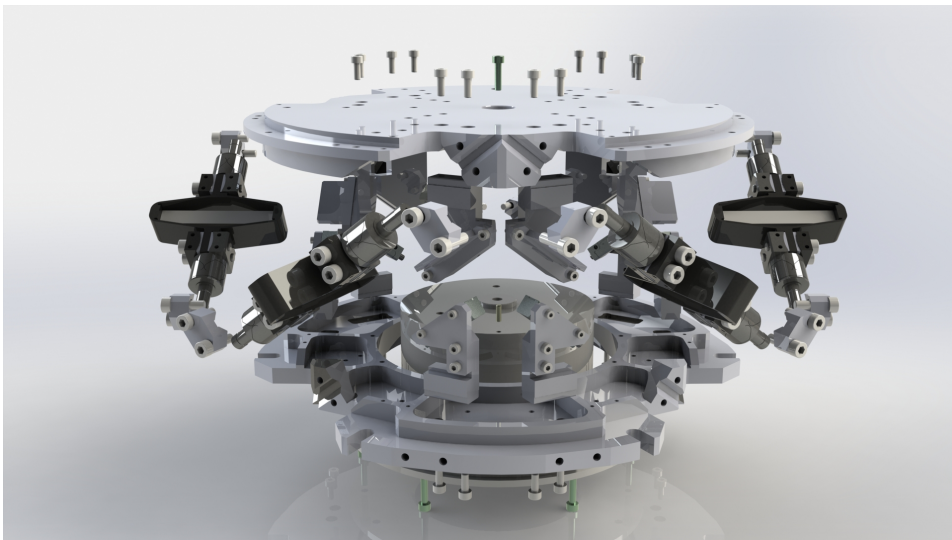
- Identify Dynamics
- Tune Model
- Flexible joints effects
- Encoder effect



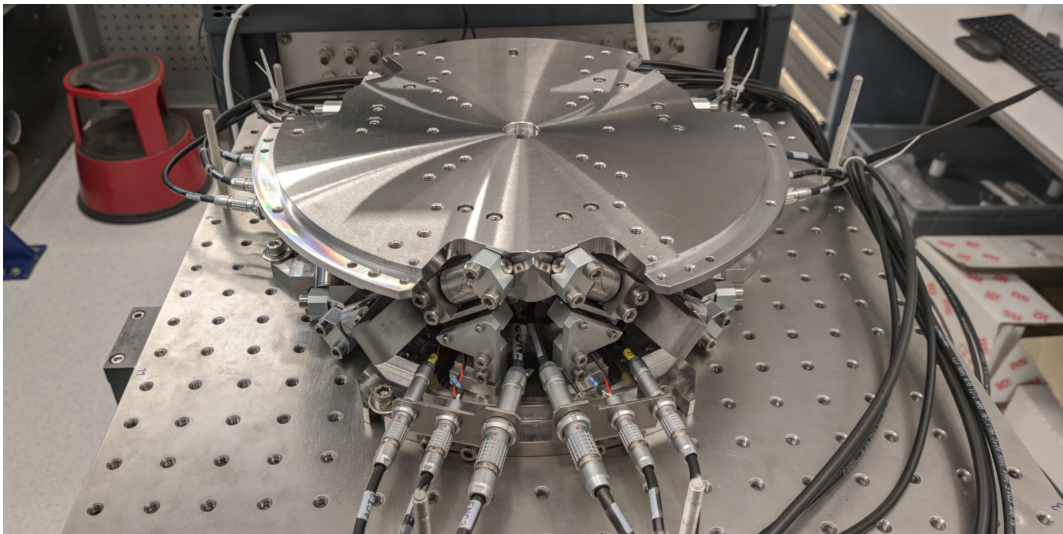
Strut - Encoders Output and Spurious Modes



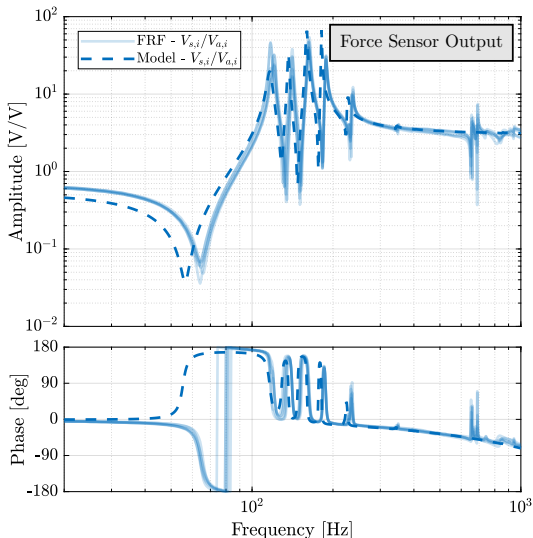
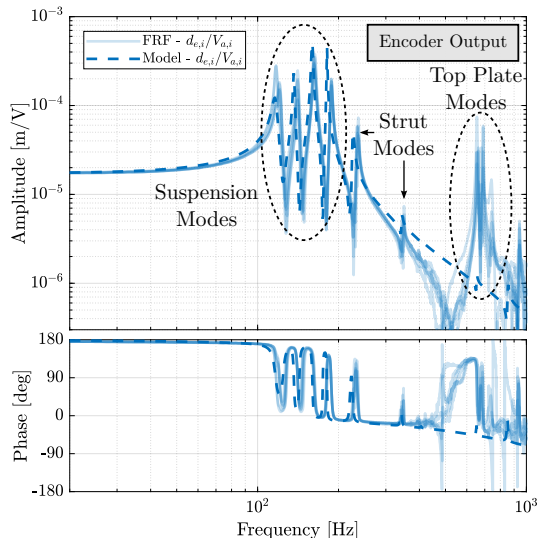
Nano-Hexapod Mounting Tool



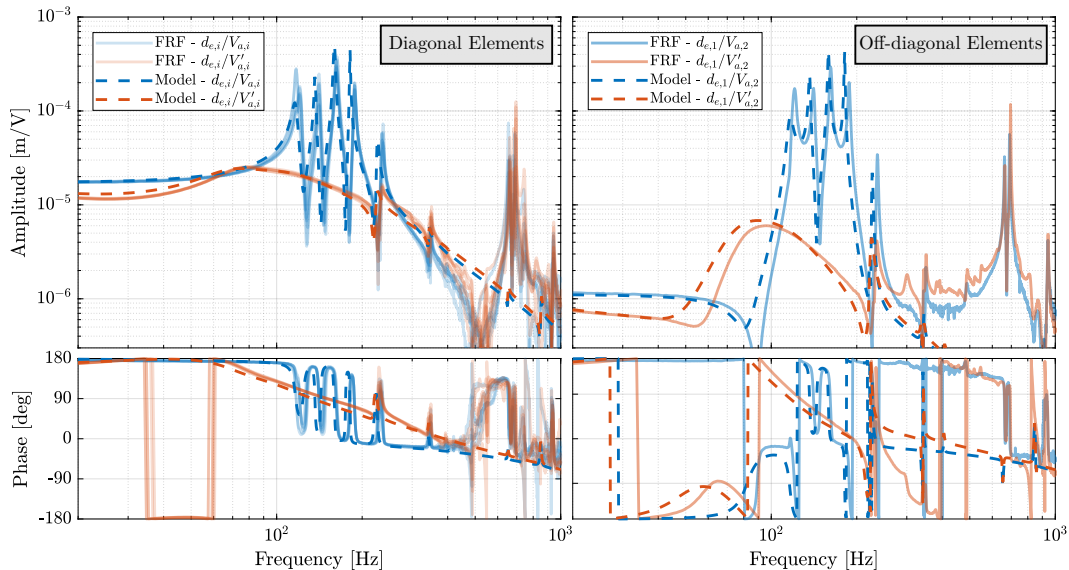
Mounted Nano-Hexapod



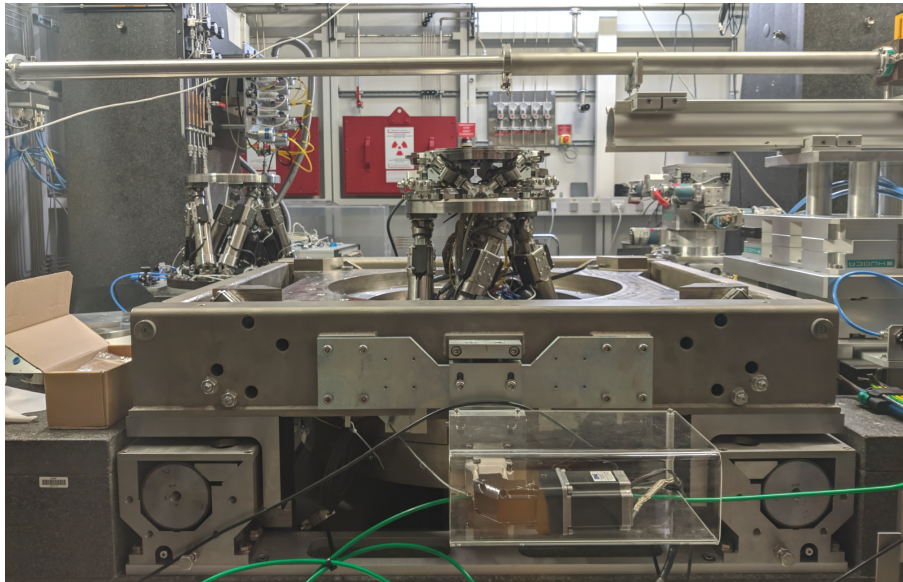
Nano-Hexapod - Identified Dynamics (Diagonal elements)



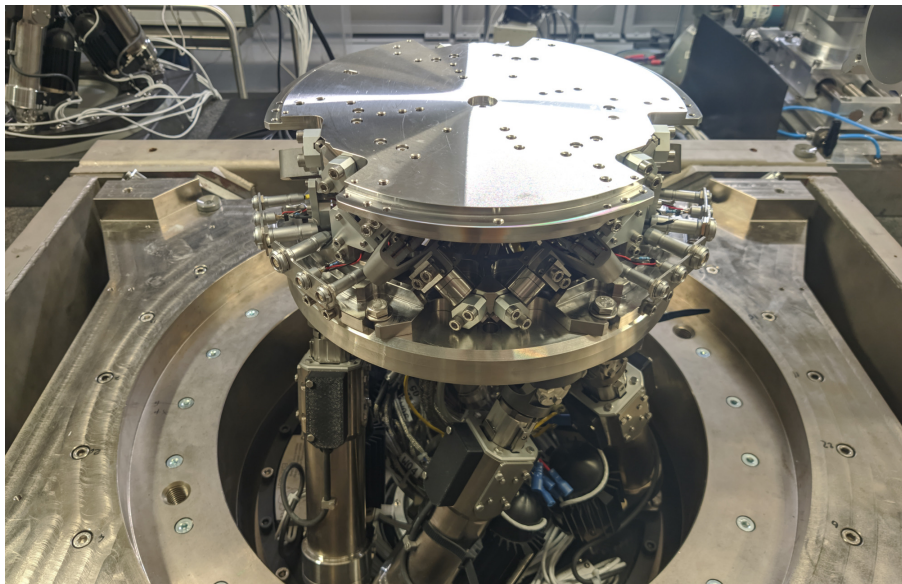
Nano-Hexapod - Damped Dynamics



The Nano-Hexapod on top of the Micro-Station



The Nano-Hexapod on top of the Micro-Station



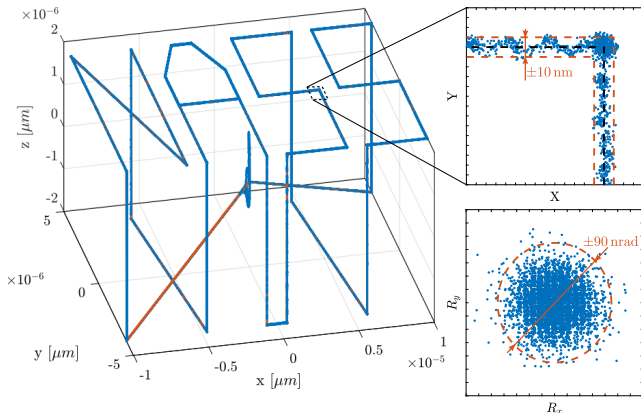
Conclusion

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



Many thanks to

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Damien Coulon and the whole team