MECHATRONICS APPROACH FOR THE DEVELOPMENT OF A NANO-ACTIVE-STABILIZATION-SYSTEM

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Abstract

With the growing number of fourth generation light sources, there is an increased need of fast positioning end-stations with nanometric precision. Such systems are usually including dedicated control strategies, and many factors may limit their performances. In order to design such complex systems in a predictive way, a mechatronic design approach also known as "model based design", may be utilized. In this paper, we present how this mechatronic design approach was used for the development of a nano-hexapod for the ESRF ID31 beamline. The chosen design approach consists of using models of the mechatronic system (including sensors, actuators and control strategies) to predict its behavior. Based on this behavior and closed-loop simulations, the elements that are limiting the performances can be identified and re-designed accordingly. This allows to make adequate choices concerning the design of the nano-hexapod and the overall mechatronic architecture early in the project and save precious time and resources. Several test benches were used to validate the models and to gain confidence on the predictability of the final system's performances. Measured nano-hexapod's dynamics was shown to be in very good agreement with the models. Further tests should be done in order to confirm that the performances of the system match the predicted one. The presented development approach is foreseen to be applied more frequently to future mechatronic system design at the ESRF.

INTRODUCTION

[1] [2] [3] [4] [5]

NANO ACTIVE STABILIZATION SYSTEM

The Nano Active Stabilization System (NASS) is a system whose goal is to improve the positioning accuracy of an existing positioning station (the "micro-station") used on ID31.

It is represented in Figure 1 and consists of three main elements:

- the nano-hexapod located between the sample to be positioned and the micro-station.
- a interferometric metrology system measuring the sample's position with respect to the focusing optics
- a control system, which base on the measured position, properly actuates the nano-hexapod in order to stabilize the sample's position

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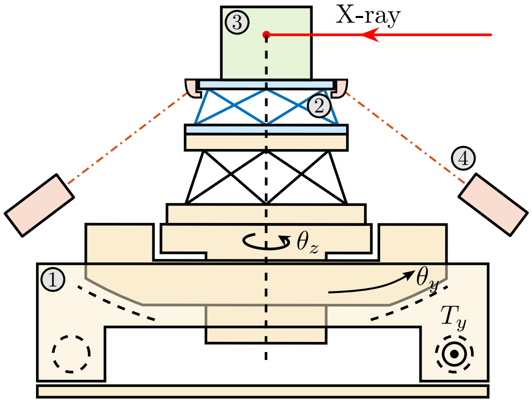

Figure 1: Nano Active Stabilization System - Schematic representation. 1) micro-station, 2) nano-hexapod, 3) sample, 4) metrology system

MECHATRONIC APPROACH

An overview of the mechatronic approach is schematically shown in Figure 2. It consists of three main phases. First the conceptual phase, where simple models and used, and the

Once the concept is validated, the detail design phase

Finally, there is the experimental phase in which the nano-hexapod is mounted, and several test benches are used to confirm the behavior of each individual elements.

Several models are used throughout all the project. At the beginning of the conceptual phase, simple "mass-spring-dampers" models (Figure 3a) were used to gain some understanding of the trade-offs. It has been concluded that a rather soft nano-hexapod

These models are very easy to use, and

Rapidly, a multi-body model (Figure 3b)

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During the detail design phase, the nano-hexapod model can be easily updated by importing the 3D parts exported from the CAD software. The key elements of the nano-hexapod such as the flexible joints and the APA are optimized using a Finite Element Software. As the flexible modes of the system are what generally limit the controller bandwidth, they are important to model in order to understand which are problematic and which are to be maximized. In order to do so, a "super-element" can be exported and imported in Simscape (Figure 3c)

☐ Table that compares the three models in terms of:

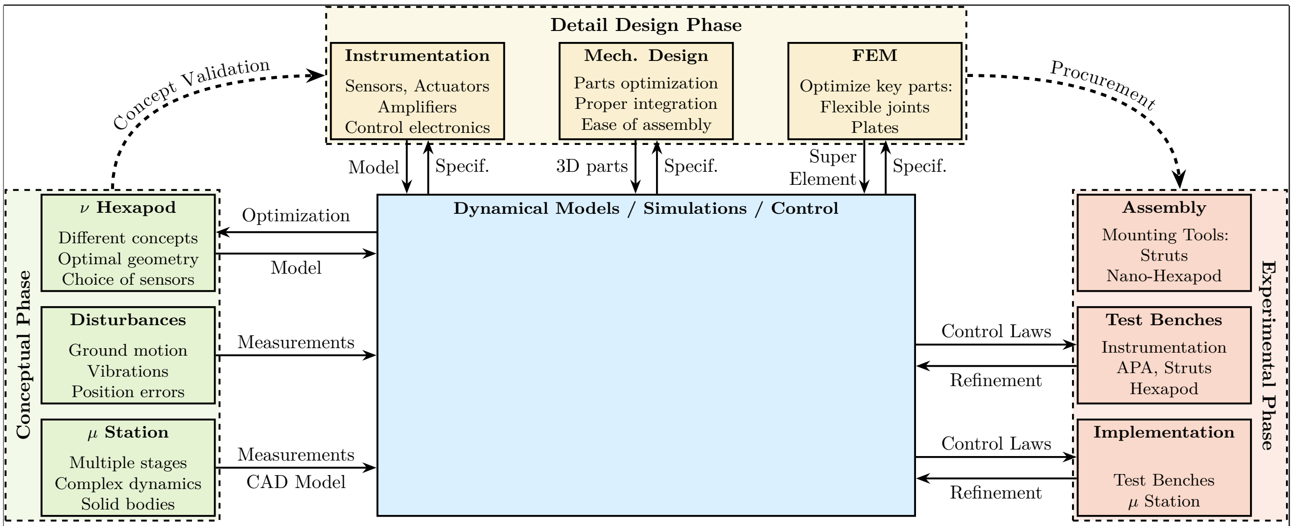

Figure 2: Overview of the mechatronic approach

- time simulation
- FRF
- accuracy
- easy to use

During the experimental phase, the models are refined using the measurements. The models are stiff very useful to understand the measurements and the associated limitations. They are used to have a better insight on which measures to take in order to overcome the current limitations.

For instance, it has been found that when fixing encoders to the struts (Figure 4), several flexible modes of the APA were appearing the dynamics which render the control using the encoders very complex. Therefore, an alternative configuration with the encoders fixed to the plates instead was used.

NANO-HEXAPOD DESIGN

TEST-BENCHES

Several test benches were used for all the critical elements of the nano-hexapod. For instant, the bending stiffness of the flexible joints are measured, and the model is refined. The measurement noise of the encoders are also measured, and the input/output relationship and the output voltage noise of the voltage amplifiers are measured.

Perhaps the most important test bench was the one used to identify the dynamics of the amplified piezoelectric actuator (shown in Figure 7). It consist of a 5 kg granite vertical guided with an air bearing and fixed on top of the APA. An excitation signal (low pass filtered white noise) is generated and applied to two of the piezoelectric stacks. Both the voltage generated by the third piezoelectric stack and the displacement measured by the encoder are recorded. The two obtained FRF can then be compared with the model and the piezoelectric constant are identified. These constants are used to do the conversion from the mechanical domain (force, strain) easily accessible on the model to the electrical domain (voltages, charges) easily measured. After identification of these constant, the match between the measured FRF and the model dynamics is quite good (Figure 8)

The same bench was also used with the struts in order to study the effects of the flexible joints.

CONTROL RESULTS

CONCLUSION

ACKNOWLEDGMENTS

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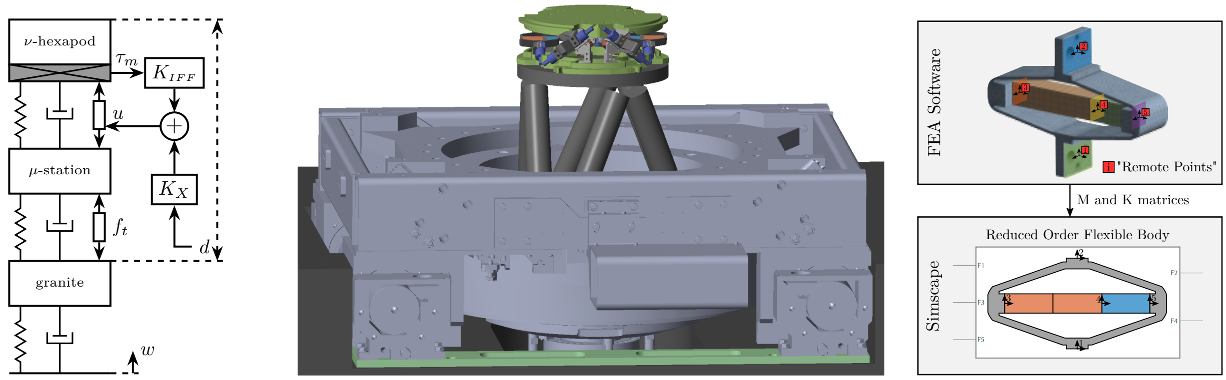

(a) Mass Spring Damper model (b) Multi Body model (c) Finite Element Model

Figure 3: Models used during all the design process. From (a), (b), (c)

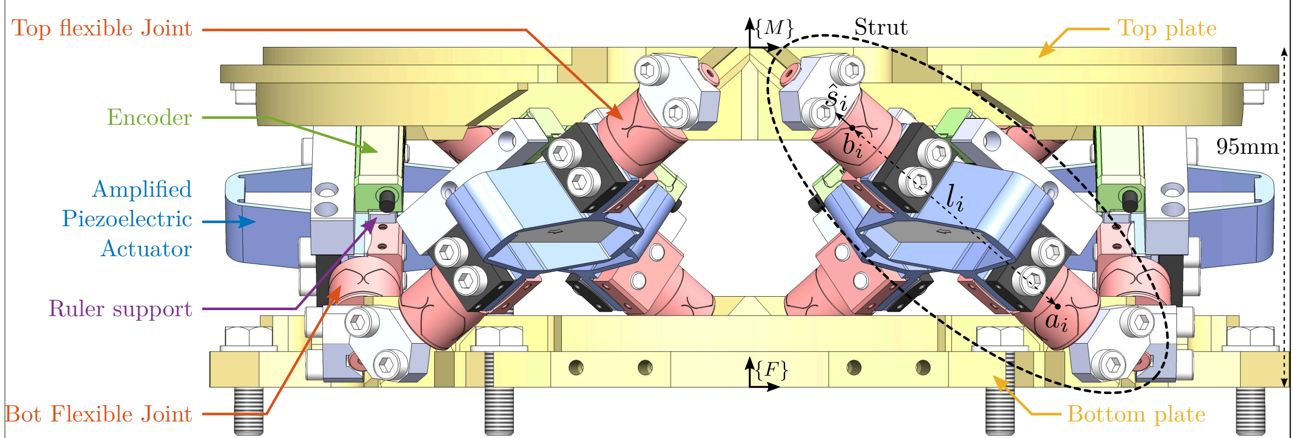

Figure 4: CAD view of the nano-hexapod with key elements

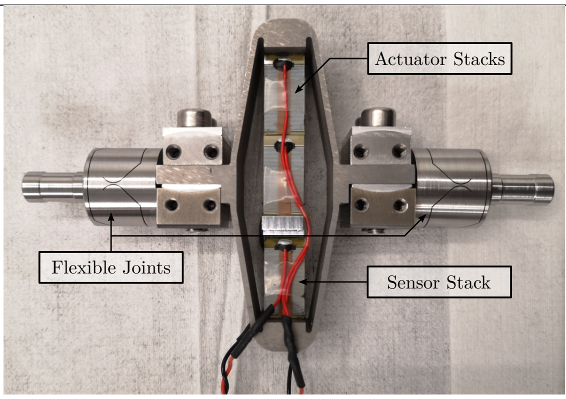

Figure 5: Picture of a nano-hexapod's strut

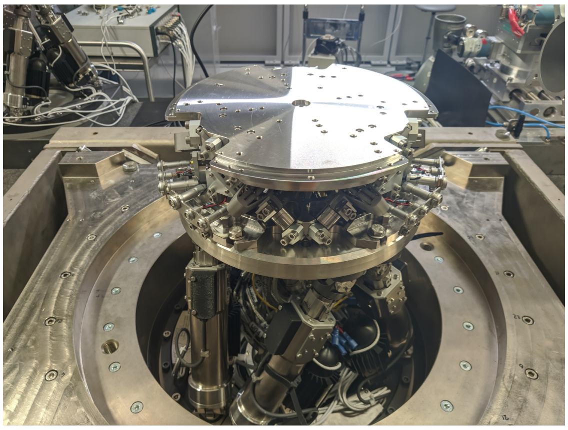

Figure 6: Picture of the Nano-Hexapod on top of the ID31 micro-station

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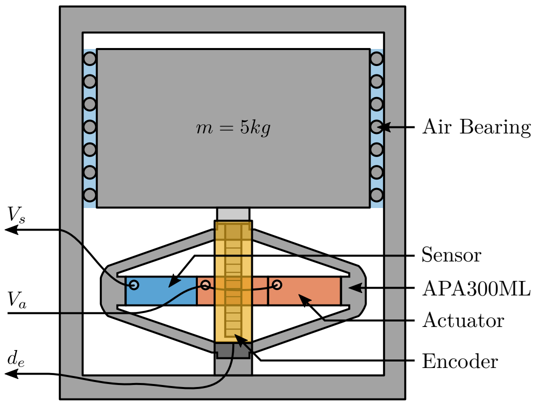


Figure 7: Schematic of the bench used to identify the APA dynamics

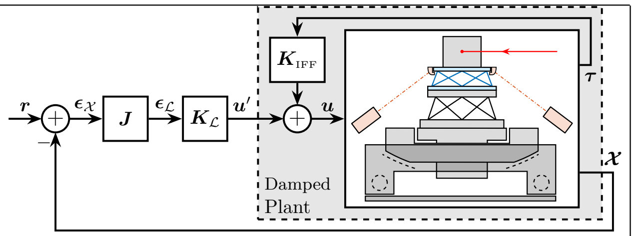
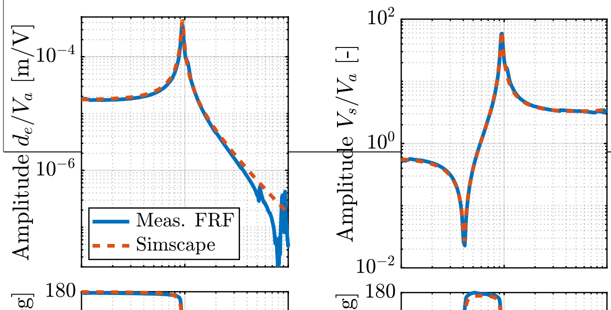
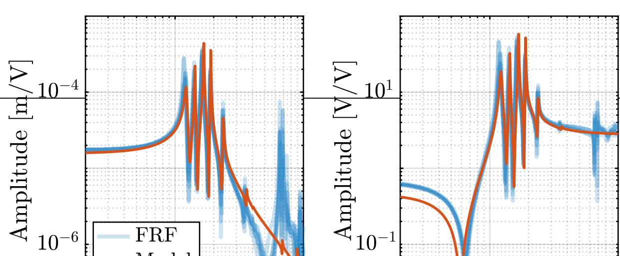


Figure 9: HAC-LAC Strategy - Block Diagram. The signals are: $\boldsymbol{r}$ the wanted sample's position, $\boldsymbol{X}$ the measured sample's position, $\boldsymbol{\epsilon}_{\mathcal{X}}$ the sample's position error, $\boldsymbol{\epsilon}_{\mathcal{L}}$ the sample position error expressed in the "frame" of the nano-hexapod struts, $\boldsymbol{u}$ the generated DAC voltages applied to the voltage amplifiers and then to the piezoelectric actuator stacks, $\boldsymbol{u}'$ the new inputs corresponding to the damped plant, $\boldsymbol{\tau}$ the measured sensor stack voltages. $\boldsymbol{T}$ is . $\boldsymbol{K}_{IFF}$ is the Low Authority Controller used for active damping. $\boldsymbol{K}_L$ is the High Authority Controller.





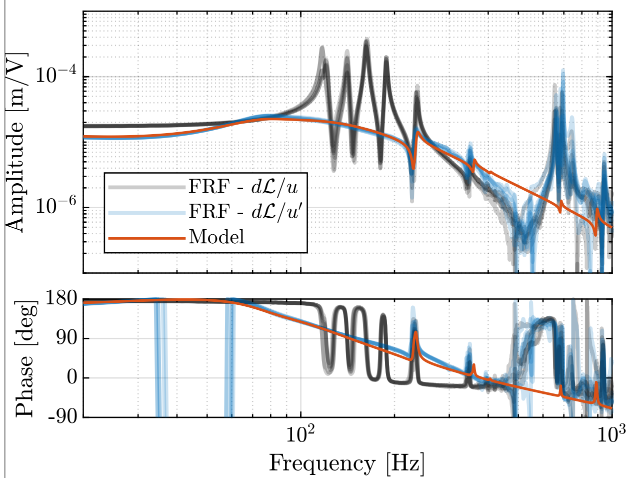


Figure 11: Undamped and Damped plant using IFF (measured FRF and Simscape model).