Mechatronics Concepts for the New High-Dynamics DCM for Sirius

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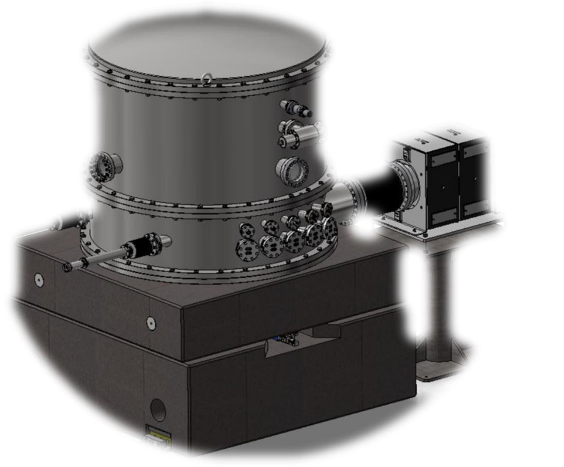
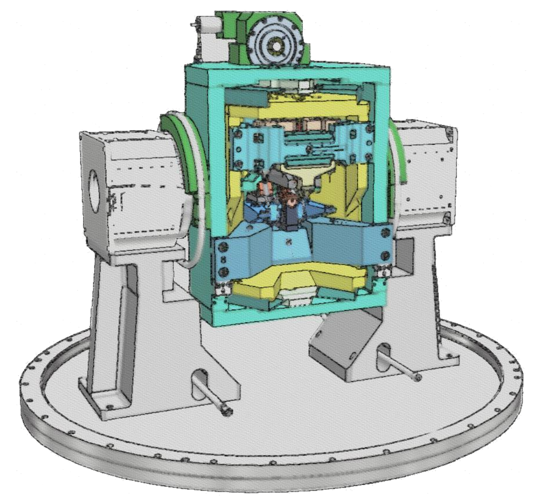


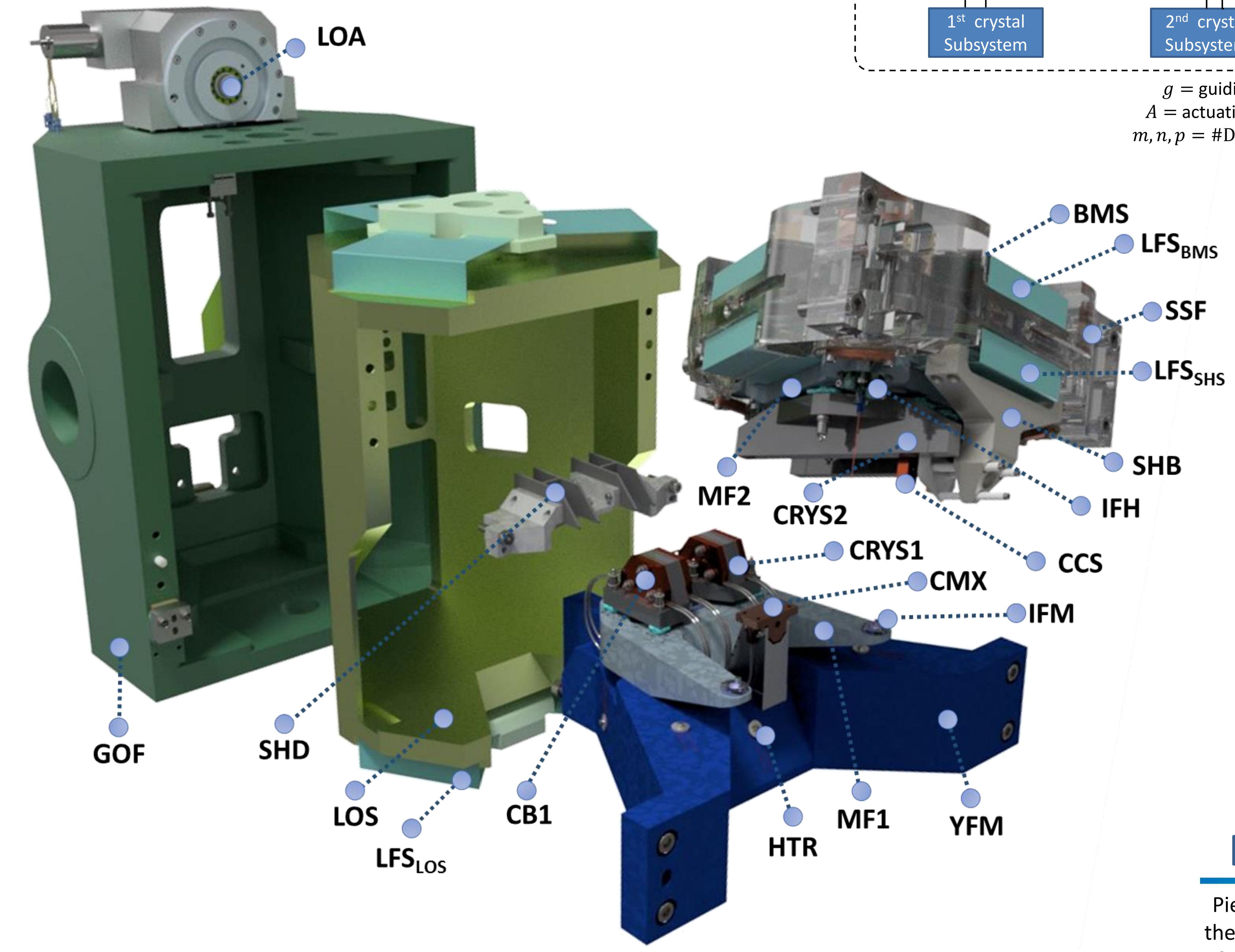


Abstract

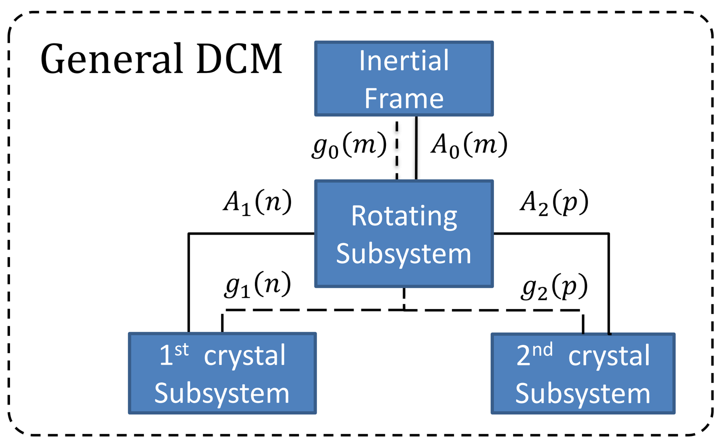
The monochromator is known to be one of the most critical optical elements of a synchrotron beamline, since it directly affects the beam quality with respect to energy and position. Naturally, the new 4th generation machines, with emittances in the range of order of 100 pm rad, require even higher stability performances, in spite of the still conflicting factors such as high power loads, power load variation, and vibration sources. A new high-dynamics DCM (Double Crystal Monochromator) is under development at the Brazilian Synchrotron Light Laboratory for the future X-ray undulator and superbend beamlines of Sirius, the new Brazilian 4th generation synchrotron [1, 2]. Aiming at an inter-crystal stability of a few tens of nrad (even during the Bragg angle motion for flyscans) and considering the limitations of the current DCM implementations, several aspects of the DCM engineering are being revisited. The system concept is chosen such that a control bandwidth above 200 Hz can be achieved. This requires well designed system dynamics, which can be realized by properly combining stiff and compliant elements. As a result, a lot of the known disturbances can be attenuated or suppressed, as well as internally excited modes can be effectively handled. The mechatronics concepts and analyses, including the metrological details, are shown.

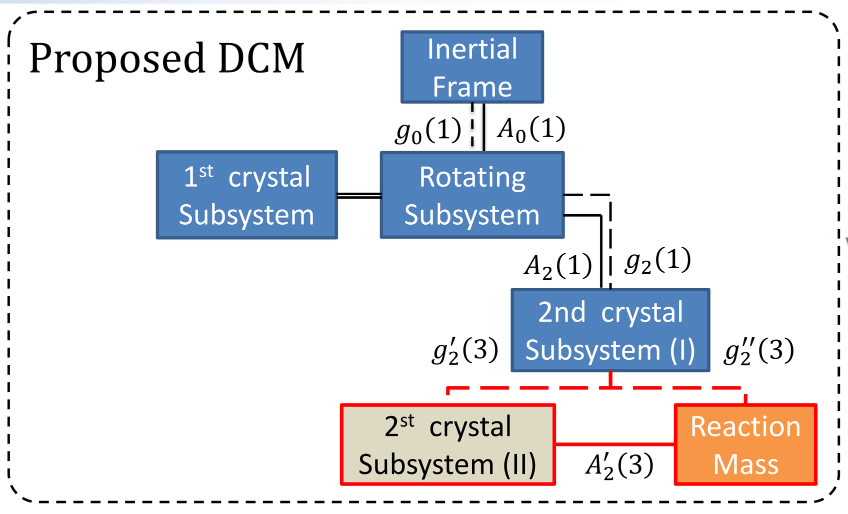
Introduction

At the new 4th generation synchrotrons, the performance of many X-ray beamlines may be critically affected be the stability performance of the DCMs . Even though some incremental progress has been achieved in mitigating well-known vibration sources such as the cooling system, experimental floor vibrations, and even self-induced disturbances [3, 4], it is believed that the required stability numbers for DCMs cannot be achieved without a few design conceptual changes, most of which is related to a high-bandwidth closed-loop control target .

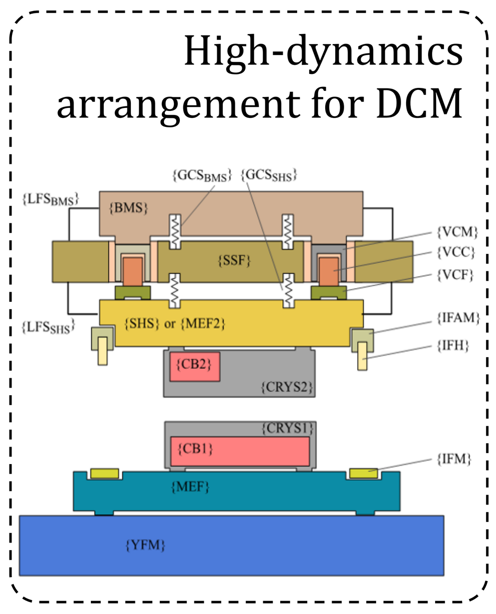


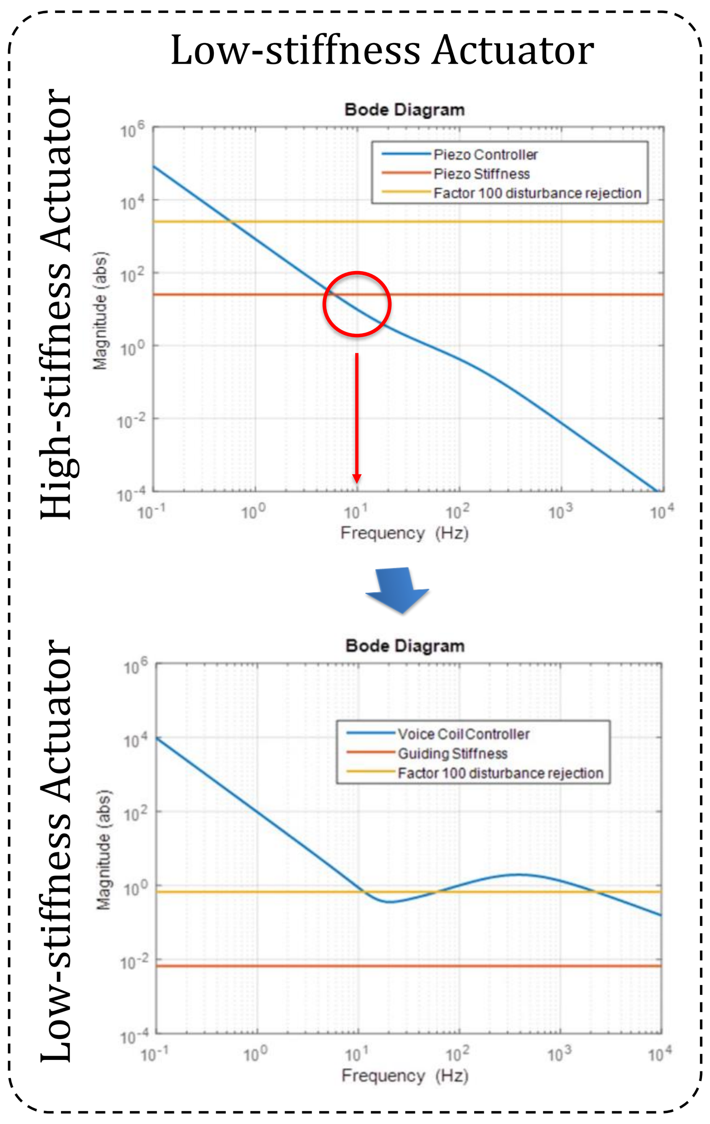
High-Dynamics Concept

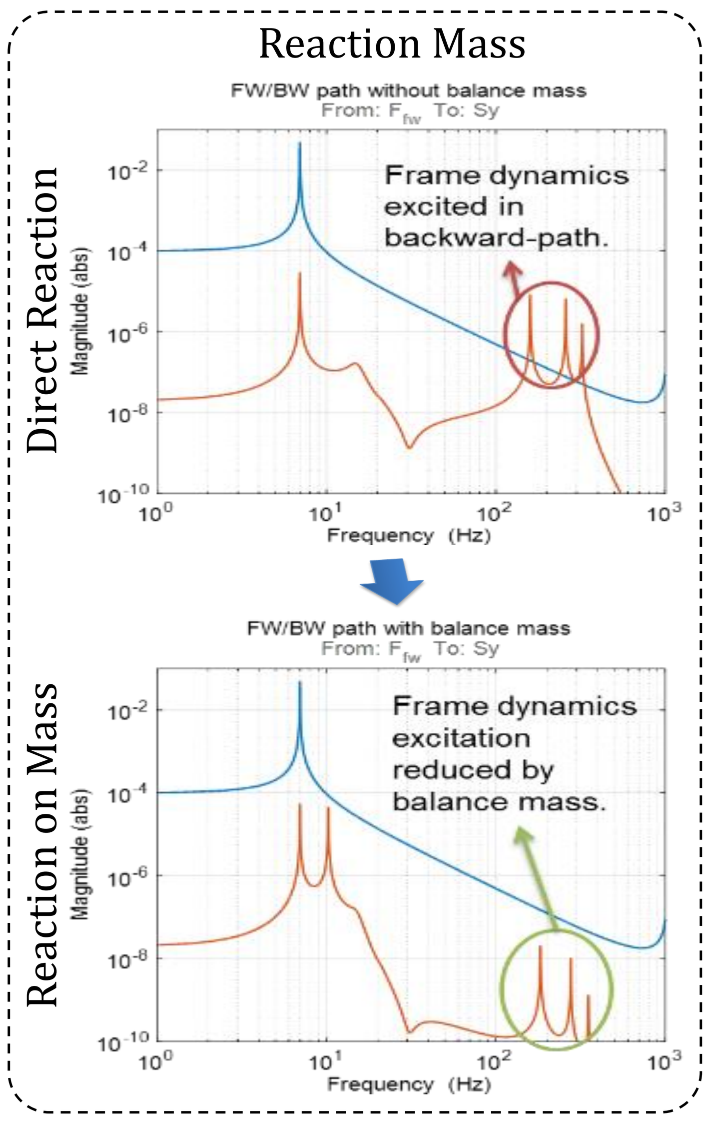




g = guiding
A = actuation
m, n, p = #DoF







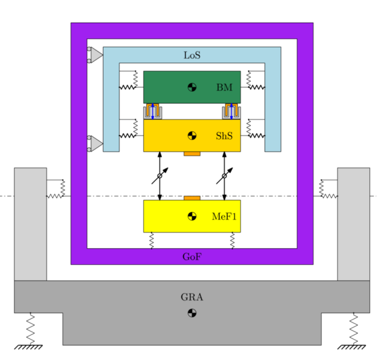
Force Actuation Concept

Piezoelectric actuators are position based actuators and stiff elements by definition. For that reason, the control gain is relatively limited, and the closed-loop bandwidth estimated to be only in the order of a few tens of Hz. On the other hand, low-stiffness actuators, as voice-coils, allow for a more robust control, with closed-loop bandwidth that may reach few hundreds of Hz. The table below compares the performance of the system, according to the dynamic model, for voice-coils and standard piezo actuators.

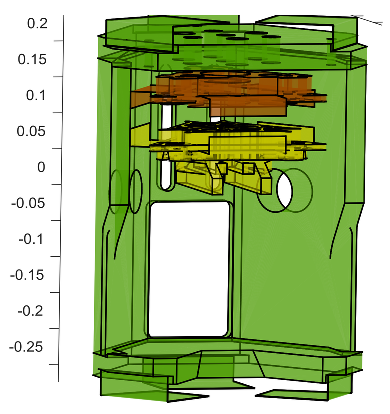
Error RX budget	Lorentz nrad (3σ)		Piezostack nrad (3σ)	Piezowalker nrad (3σ)
Servo bandwidth	**150 Hz**	**200 Hz**	**20 Hz**	**20 Hz**
Floor vibrations	1.8	0.8	2.5	0.9
Goniometer/LoS disturbances	✓		×	×
LN2 → Crystal deformation & Servo-error	?	?	?	?
Vibration on vessel / acoustic vibrations	?	?	?	?
Amplifier noise	2.1 *	1.4 *	44.1	2.9
Amplifier DAC quantizatio	0.3	0.2	0.2	0.2
DMI quantization/synchronisation errors (**)	(0.1)	(0.2)	(0.1)	(0.1)
Quadratic sum (nrad, 3σ)	2.8	1.6	44.1	3.1
	Fly scan ✓		Range not feasible ×	No fly scan ×

(*) Amplifier selection not made yet
(**) Metrology budget

Scaled Approach for Control Design



- ✓ 1D Model Analysis
- ✓ Dynamic analysis
- ✓ Disturbances influences
- ✓ Amplifiers noise
- ✓ Sensor quantization
- ✓ LN2 flow-induced vibrations

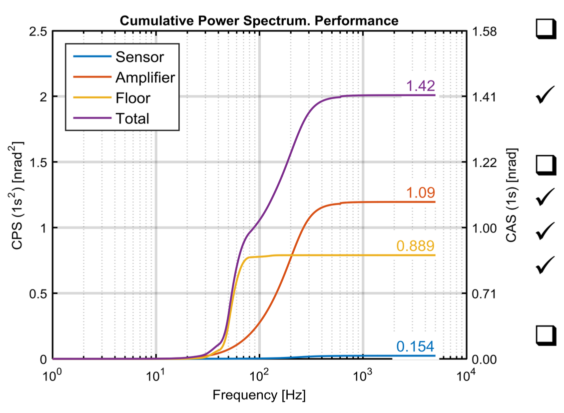


- ✓ Rotation errors
- ✓ Alignment errors
- ✓ Structures Eigen modes analysis
- ✓ Actuators and sensors placement (co-located control)

Control Project Design Tools

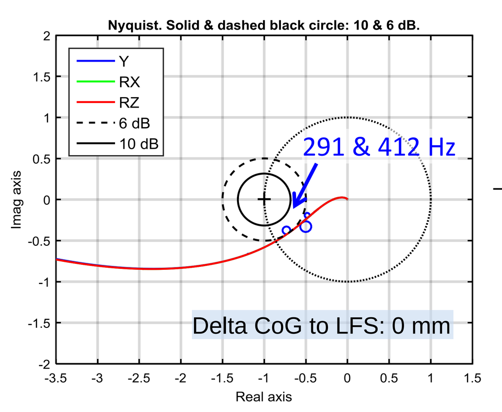
A dynamic model allows for the representation of the system in Bode plots, which reveal the mechanical performance in the frequency domain. It can also be used to verify the control sensitivity of a given control input or disturbance source. The same model is also used in Nyquist plots for evaluating and phase margin for system stability. By varying specific system parameters, the impact of stiffness, misalignments and imbalance and, for example, can be analysed.

Error Budgeting by Cumulative Power Spectrum

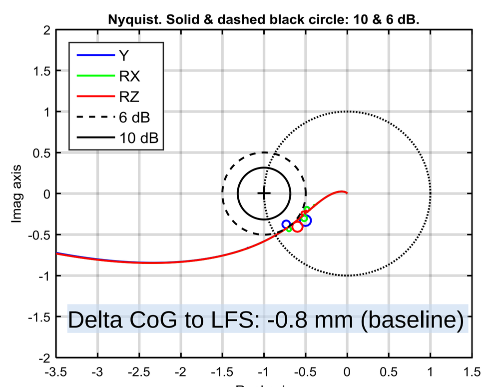


- ❑ Reported values 1σ, peak-peak: ±3σ: ±4.2 nrad
- ✓ For BW of 250 Hz (target)
- ❑ Not including yet:
- ✓ LN_2 disturbances
- ✓ Rx gonio control noise
- ✓ …
- ❑ To be verified on 6 DoF lumped mass model

Evaluation of Misalignment w.r.t. MF1



Rotation $(mrad)$	R_x	R_z
SHS	1.6	0.6
BMS	5.2	0.6



- ✓ Impact of misalignment is small;
- ✓ Two modes could become critical when damping below 0.2%: 291 & 412 Hz

Sample frequency: Phase margin – Robustness analysis

Phase loss vs. sample frequency

Sampling frequency	(kHz)	5	10	20
Desired BW	150 Hz	-5.40°	-2.70°	-1.35°
Zero-order hold	0.5 #	-10.80°	-5.40°	-2.70°
General delay	1 #	-0.11°	-0.11°	-0.11°
Attocube latency	$2x10^{-6}\ s$	-16.31°	-8.21°	-4.16°
Spec			< -10°	

- ✓ For a bandwidth of 150 Hz the sampling frequency of 10 kHz or above is required to keep sufficient robustness margin.
- ✓ Dynamic contributions, errors, and performance evaluation

Conclusion

The high-dynamics concepts that are applied in this project are already proven technology in high-end mechatronics systems, meaning that, although there is some innovation within the synchrotron community, it comes under calculated risks, based on extensive analyses and predictive modelling.

Acknowledgement

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References

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