Thermal Management and Crystal Clamping for the New High-Dynamics DCM for Sirius

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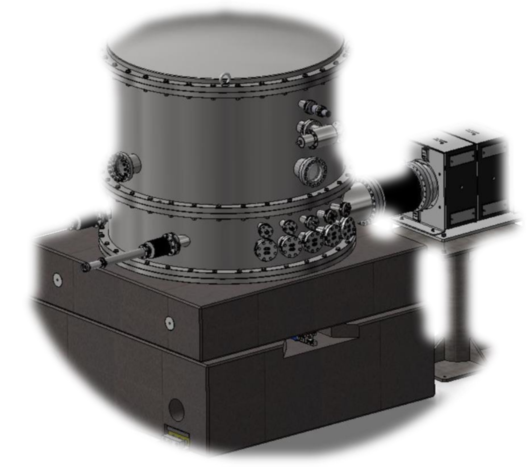
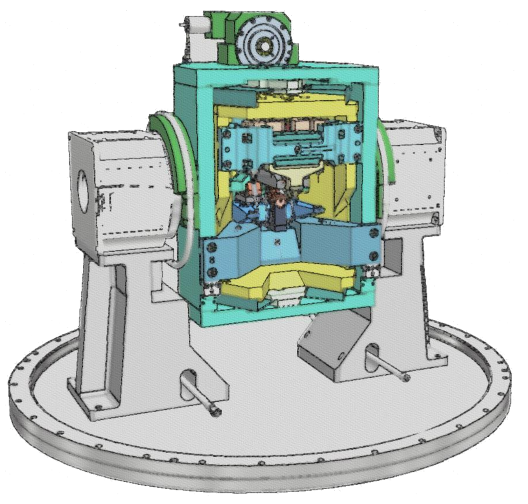


Abstract

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]. In order to achieve high-bandwidth control and stability of a few nrad, as well as to prevent unpredicted mounting and clamping distortions, new solutions are proposed for crystal fixation and thermal management. The design is based on flexural elements, aiming for a highly predictable performance, like support stiffness, crystal distortion and thermal insulation. It was optimised by using mechanical and thermal FEA, including CFD. Efforts were made to predict thermal boundaries associated with the synchrotron beam, including incident, diffracted and scattered power, for which the undulator spectrum was employed in the Monte Carlo simulation package – FLUKA.

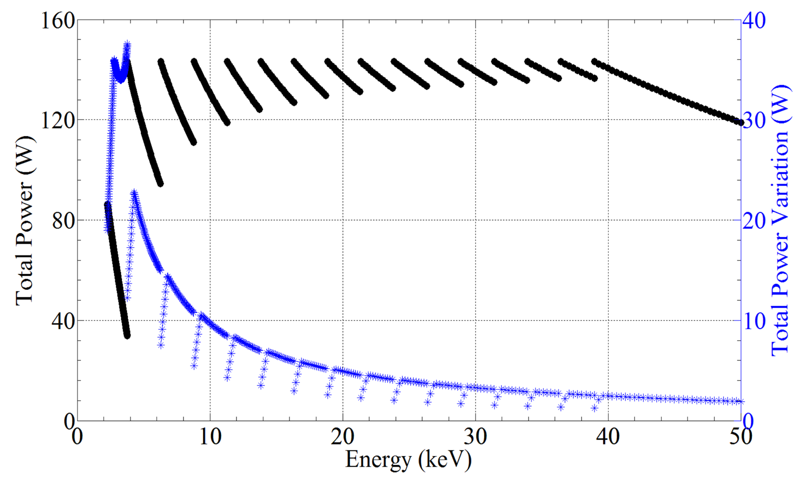


Introduction

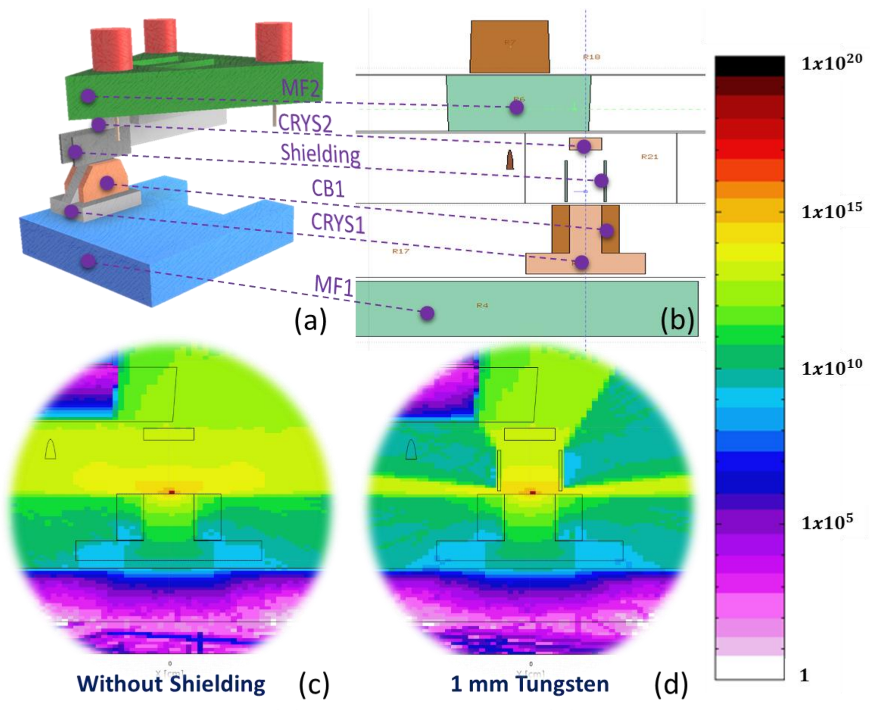
The goal of this work is to present the thermal management and the mechanical clamping concepts for the new high stability DCM for Sirius.

Thermal Management

- ❑ Power load evaluation:
  - ✓ IVU spectrum simulation using radiation calculation tools: total incident power and power variation for energy scans as function of energy;
  - ✓ Scattering and absorption using Monte Carlo simulation: shielding design, radiation dose estimates and energy deposition;
  - ✓ Diffracted power by numerical estimate;
  - ✓ Black body radiation using FEA.
- ❑ Solutions:
  - ✓ LN_2 cryogenic cooling architecture;
  - ✓ Low-flow design for improved HTC and vibration performance;
  - ✓ Thermal contact enhancement and strain reduction by indium interface;
  - ✓ Mounting flexures as effective thermal barriers;
  - ✓ Flexible copper straps for thermal links;
  - ✓ Low-power distributed foil heaters for active temperature control.
- ❑ Lumped-mass thermal model:
  - ✓ Conductance design by hand-calculation and FEA.



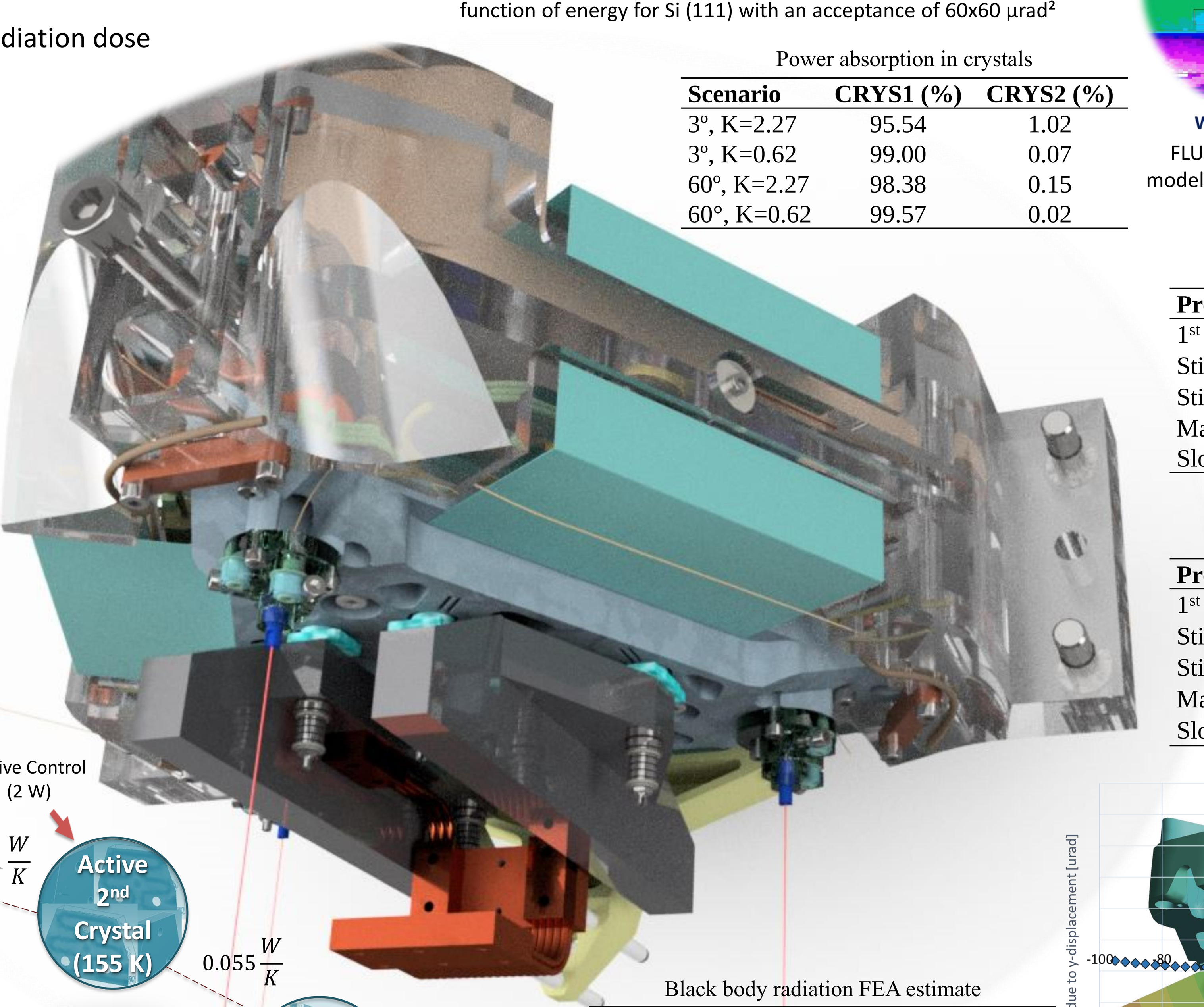
Incident power and power variation in ±0.5 keV scans as a function of energy for Si (111) with an acceptance of 60x60 µrad²



FLUKA simulations: (a) original CAD model; (b) upstream view of the model in FLUKA; (c) and (d) upstream view of photon track length density (Particles/cm²/s) without and with shielding

Power absorption in crystals

Scenario	CRYS1 (%)	CRYS2 (%)
3º, K=2.27	95.54	1.02
3º, K=0.62	99.00	0.07
60º, K=2.27	98.38	0.15
60°, K=0.62	99.57	0.02

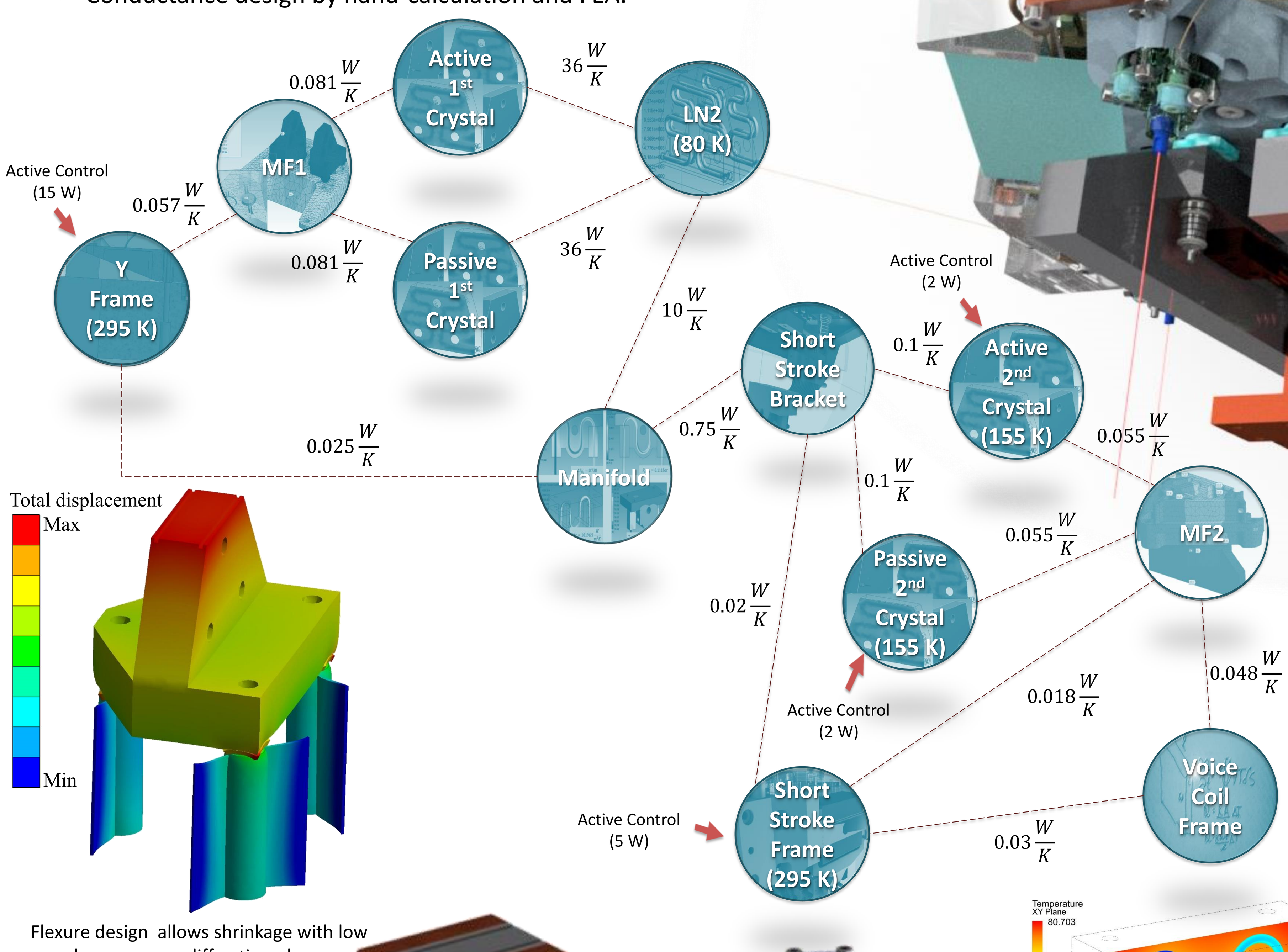


Clamping and shrinkage effects in CRYS1

Property	Value
1st Eigen Frequency	1.7 kHz
Stiffness in stiff direction (x3)	$2x10^8$ Nm^{-1}
Stiffness in compliant direction	$1x10^6$ Nm^{-1}
Maximum principal stress in CRYS1	0.14 MPa
Slope error on footprint (θ=3°)	<0.12 µrad

Clamping and shrinkage effects in CRYS2

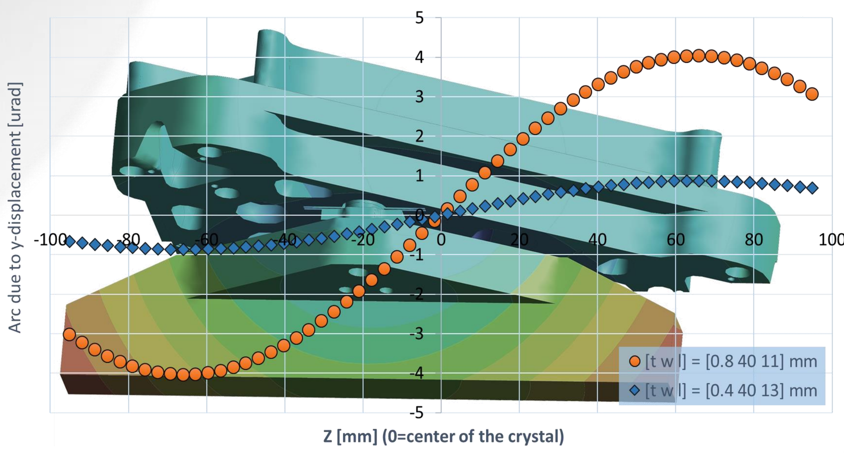
Property	Value
1st Eigen Frequency	1.7 kHz
Stiffness in stiff direction (x3)	$1x10^8$ Nm^{-1}
Stiffness in compliant direction	$1x10^5$ Nm^{-1}
Maximum principal stress in CRYS2	1.4 MPa
Slope error on footprint (θ=3°)	0.19 µrad



Black body radiation FEA estimate

Element	Temperature (K)	FEA Result (W)
CRYS1	80	0.4
MF1	150	3.8
CRYS2	155	0.9
MF2	213	2.7

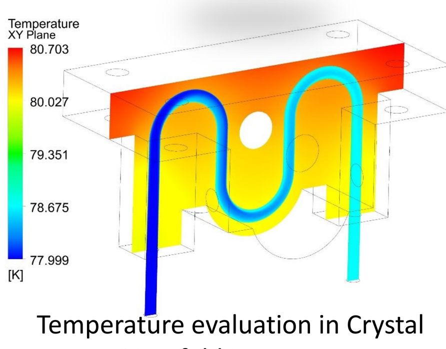
Flexure design allows shrinkage with low slope error on diffraction plane



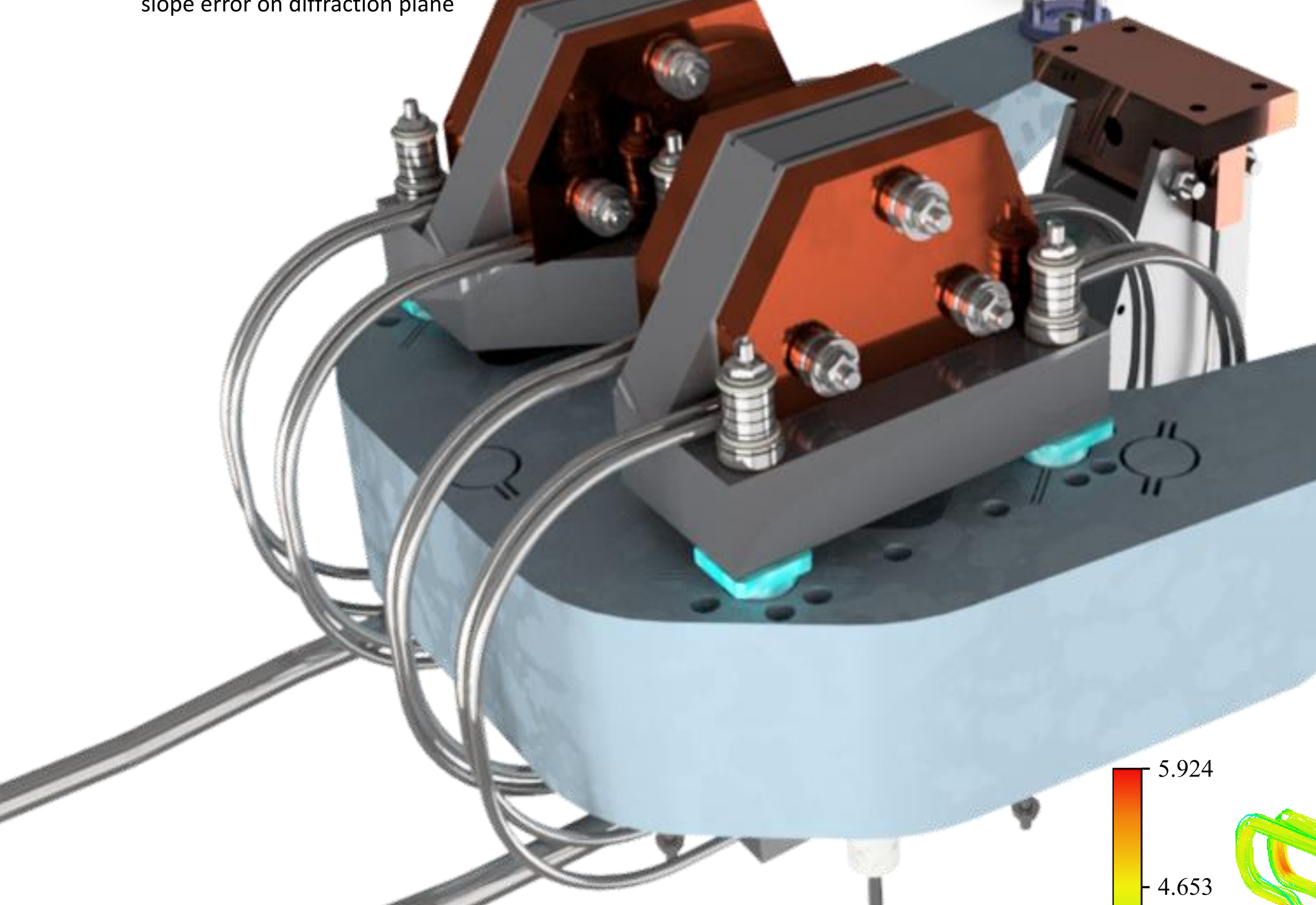
Meridional slope on diffraction plane for two different flexure dimensions: [t w l]=[0.8 40 11] and [0.4 40 13] mm

Clamping Concepts

- ❑ Wire eroded flexures:
  - ✓ Deterministic design for high stiffness with thermal expansion compatibility;
  - ✓ Optimized relation between stiffness and thermal conductance.
- ❑ Preload solution:
  - ✓ Quasi-constant clamping forces over thermal expansion;
  - ✓ Fastener with suitable composition of disc washers.
- ❑ Slope error design target



Temperature evaluation in Crystal Manifold Extension



Conclusion

This work shows the thermal and clamping solutions for the new high-dynamics DCM for Sirius, which are important to guarantee the integrity and optimum performance of the crystals. Several analytical and numerical tools have been used in order to design them with specific targets regarding slope errors, thermal response, mechanical stiffness and manufacturability. This work will continue during the Detailed Design Phase and, after validation, may be extended to different systems, such as mirrors and other monochromators.

Acknowledgement

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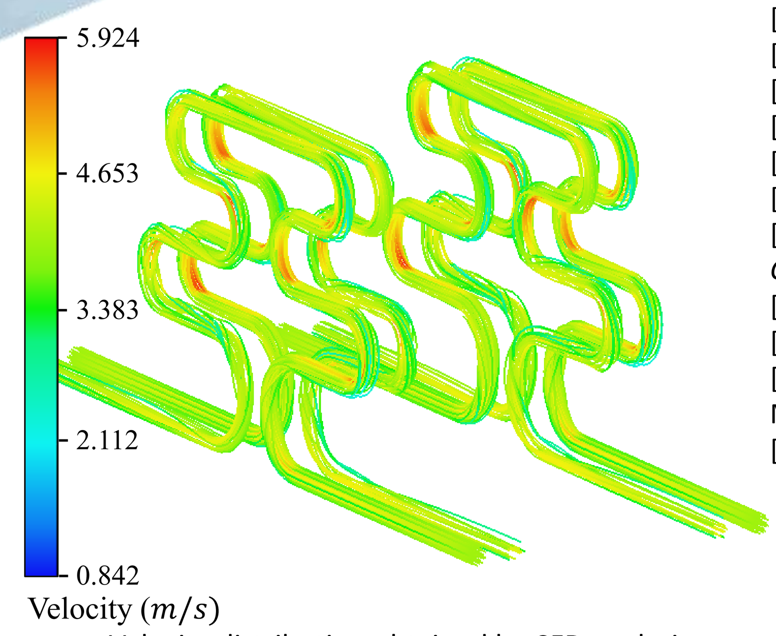
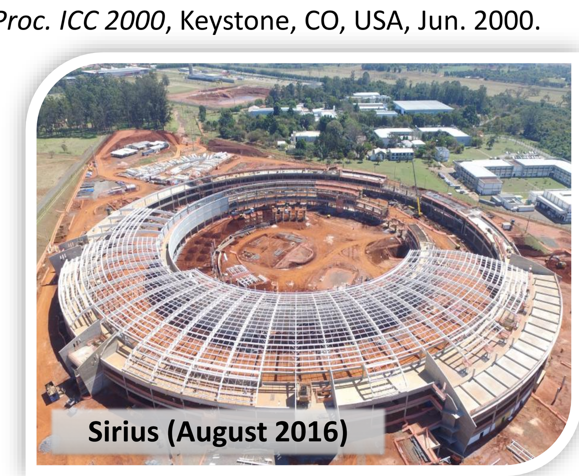
Cooling Prototype



Velocity distribution obtained by CFD analysis.



Sirius (August 2016)

MEDSI 2016
MECHANICAL ENGINEERING DESIGN OF SYNCHROTRON RADIATION EQUIPMENT AND INSTRUMENTATION

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