ISBN: 978-3-95450-250-9 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2023-TUPYP008

EXACTLY CONSTRAINED, HIGH HEAT LOAD DESIGN FOR SABIA'S FIRST MIRROR*

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Abstract

The SABIA beamline (Soft x-ray ABsorption spectroscopy and ImAging) will operate in a range of 100 to 2000 eV and will perform XPS, PEEM and XMCD techniques at SIRIUS/LNLS. Thermal management on these soft x-ray beamlines is particularly challenging due to the high heat loads. SABIA's first mirror (M1) absorbs about 360 W, with a maximum power density of 0.52 W/mm², and a water-cooled mirror was designed to handle this substantial heat load. To prolong the mirror operation lifetime, often shortened on soft X-ray beamlines due to carbon deposition on the mirror optical surface, a procedure was adopted using high partial pressure of O_2 into the vacuum chamber during the commissioning phase. The internal mechanism was designed to be exactly constrained using folded leaf springs. It presents one degree of freedom for control and alignment: a rotation around the vertical axis with a motion range of about ±0.6 mrad, provided by a piezoelectric actuator and measured using vacuum compatible linear encoders. This work describes the SABIA's M1 exactly constrained, high heat absorbent design, its safety particularities compared to SIRIUS typical mirrors, and validation tests results.

INTRODUCTION

Unique challenges emerged with the introduction of innovative optics instruments such as DCML [1] and the exactly constrained mirrors for the Sirius facility. The solution for SABIA's first mirror consists of an exactly constrained side bounce mirror [2] with direct internal cooling. The technical commission of SABIA Beamline (SAB) started on the early 2023. The beamline optical layout is shown on Figure 1.

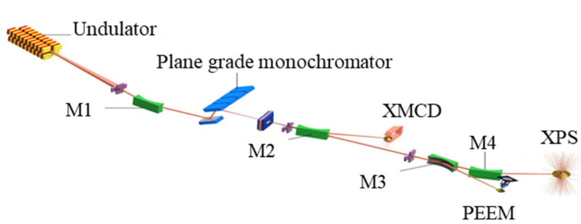

Figure 1: SABIA's optical layout.

Internal water cooling is not new for the synchrotron community, it has been proposed as a solution for previous generation sources heat management [3] but it still been used by some of the major manufacturers [4] as it can manage high heat load. Hose connections pose electronic and vacuum safety challenges, demanding meticulous mechanical isolation and leak protection. We looked at this with special attention to ensure both safety in case of coolant leakage, and mechanical decoupling on important degrees of freedoms.

THERMO-MECHANICAL DESIGN

The SAB M1 mechanism is comprised of two main parts. The first one is the granite bench, responsible for rough alignment and mechanical support for the ultra-high-vacuum vessel [5]. The other is the multifunctional internal mechanism, as it is the mirror support, short stroke for fine alignment, thermal insulator, and thermo-mechanical deformation accommodator. The main requirements for this system's internal mechanism can be found on Table 1.

Table 1: System Summarized Specs

Description	Spec
Ry range:	> 1 mrad
Ry resolution:	< 150 nrad
Resonances:	> 100 Hz
Max beam distortion	<10% nominal size
Power load @ 300mA:	~ 360 W
Cooling scheme:	Internal water flow

Figure 2 shows the complete in-vacuum parts for this system: A) the mirror with internal water channels; B) photo-collector used as indirect beam illumination over the optical face; C) the mirror support and metrology assembly, including the frame (often called *"Patrick")*, responsible for the fine mechanical motion and metrology and thermal deformation accommodator and Folded Leaf Springs (FLS); D) optical encoders RL26BVS001C30V [6], for fine metrology; E) fine rotation motion stiff actuator N-470.U PiezoMike [7]; F) water hose and vacuum guard assembly; G) water and safety vacuum inlet/outlet.

* Work supported by Brazilian Ministry of Science, Technology, and Innovation
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12th Int. Conf. Mech. Eng. Design Synchrotron Radiat. Equip. Instrum. MEDSI2023, Beijing, China JACoW Publishing
ISBN: 978-3-95450-250-9 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2023-TUPYP008

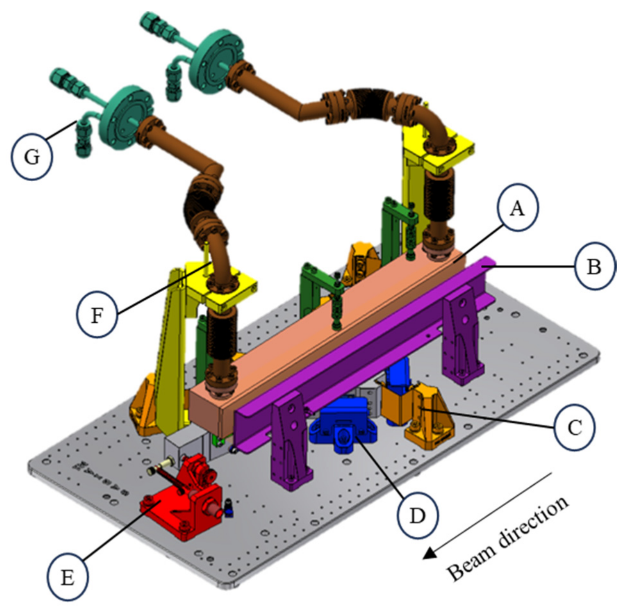

Figure 2: Complete internal mechanism of SAB M1.

Mechanical Design and Results

An optimization-based design process was adopted to improve the design, employing analytical models for a first adequate system layout, and the Finite Element Analysis method using both mechanical and thermal simulations on Ansys. By using Ansys DesignXplorer, we identified potential design enhancements, achieving greater stiffness without sacrificing motion range, despite a great computational expense. The result was an exactly constrained rotation mechanism with range of ±0.6 mrad about the vertical axis (Y axis) with a 1° natural frequency of 136 Hz.

By utilizing a flexible water hose allowed us to maintain continuous mirror rotation around the vertical axis. The hose is safeguarded by a vacuum enclosure. This dedicated low vacuum system features pressure monitoring to detect leaks, ensuring electronics and vacuum protection. Parasitic forces are minimized by anchoring the hose vacuum guard on the frame, eliminating direct forces on the water nozzle brazed to the substrate. Hose placement directs parasitic forces along the beam axis, the mirror's least sensitive direction. An upstream mask was implemented to prevent beam illumination on the side face, to protect the mirror's brazed optical face interface. Figure 3 shows the motion range scan test using the systems encoders, the motion shows little influence of the hoses on the motion range and linearity.

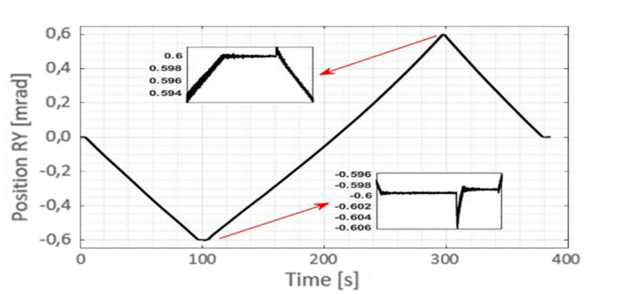

Figure 3: Mechanism motion scan.

Thermal Management

The mirror substrate was designed to incorporate internal channels allowing the cooling liquid to flow through the system. To ensure the minimal deformation possible, simulations were conducted at various flow rates, considering the manufacturer-provided pressure limits within the mirror. The smallest thermal deformation achieved was 176 nm PV, with a flow rate of 5.2 lpm at 24°C. For comparison, gravity deformations account for only 3 nm. Despite efforts to enhance the heat exchange within the system, the reduction of the cross section on the transition between the inlet and the channels resulted on the relaminarization of the flow. While larger water flux promises improved thermal performance, the elevation of internal water pressure over the optical face increases the deformations. Figure 4 shows Computational Fluid Dynamics results on the water flow and the mirror thermal gradient, besides the thermal deformation profile on caparison to gravity deformations.

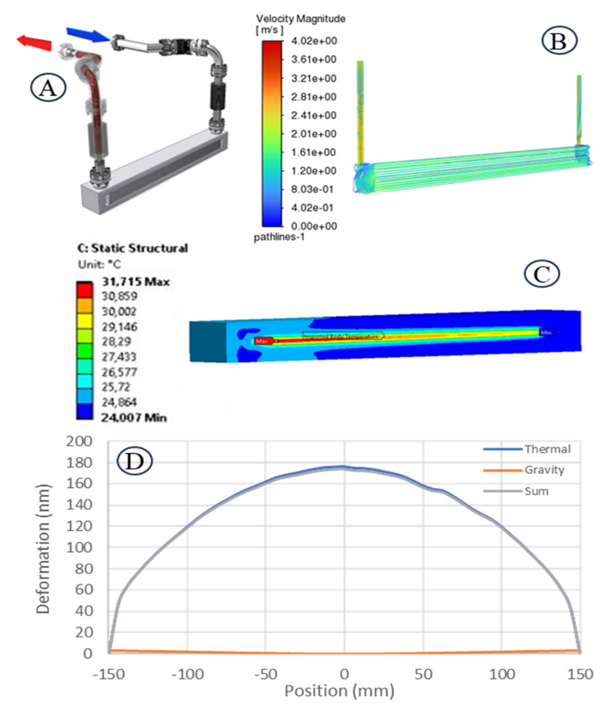

Figure 4: A) Mirror internal channels and the water hose assembly; B) Flow relaminarization due to the cross section abrupt change; C) Thermal gradient on the mirror; D) deformation profile on the optical face.

Assembly and Validation Results

The assembly and installation of this mechanisms followed the standardized procedure described on [8, 9], except for the clamping process. The mirror was glued to the mirror frame using MasterBond 42HT-2LO epoxy adhesive [10] and micro silica spheres of 53 μm to ensure a uniform glue layer using the method described on [11]. The optical surface was measured before and after the gluing to characterize the deformation induced by the glue shrinkage, since it is very complicated to be simulated. The

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comparison of the mirror deformation before and after the glue shrank down, measured in-house by a Fizeau interferometer as well as the supplier measurements, are shown on the Figure 5.

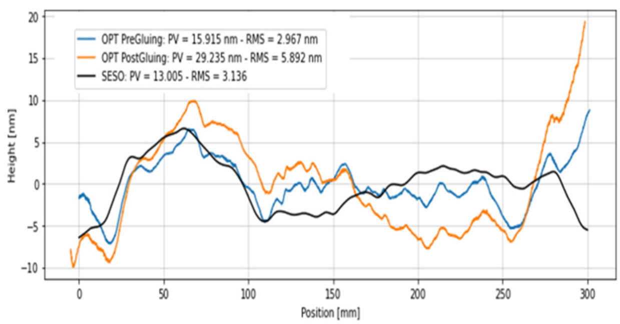

Figure 5: Heigh-error before and after the cured of the glue.

Some tests were executed to validate the mechanical performance. Modal testing was conducted before and after gluing using 3D axial 8762A5 accelerometer and PDV-100 vibrometer. By comparing test results and simulations we could identify assembly unconformities, FLS manufacturing irregularities and the effects of the glue on the dynamical performance.

The encoders were used to characterize the system stability after installation on its granite bench, in vacuum, shown on Figure 6. These tests were conducted both with the cooling system activated and deactivated, to distinguish the impact of water flow-induced vibrations. The results indicated that the cooling system increased over 35% of the mechanical instability. The system's designed and achieved performances are summarized on Table 2.

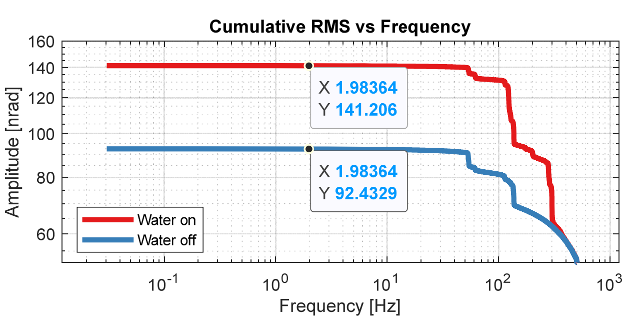

Figure 6: Cumulative amplitude spectrum of the random vibrations on the mechanism.

Table 2: Mechanism Performance

Description	Designed	Tested
Motion range [mrad]	0.604	0.6
Motion resolution [nrad]	135	129
1° Natural Frequency [Hz]	135,57	136
Stability [nrad]	--	141
Vacuum guard pressure [mbar]	1e-3	1e-8
Thermo-Mechanical deformation [nm]	173	--

Commissioning Results

During the early stages of technical commissioning, the M1 system was set under 1e-7 mbar of partial pressure of oxygen gas, as a test to slow down or prevent carbon deposition on the optical surface. Figure 7 shows a RGA monitoring of the vacuum chamber. It is possible to observe the changing on partial pressures when the system is illuminated by the photon beam, indicating that hydrocarbons and/or other carbon-based structures are reacting with the oxygen. More studies and testing are necessary to certify that this method works and how long can it prolong the mirror lifetime.

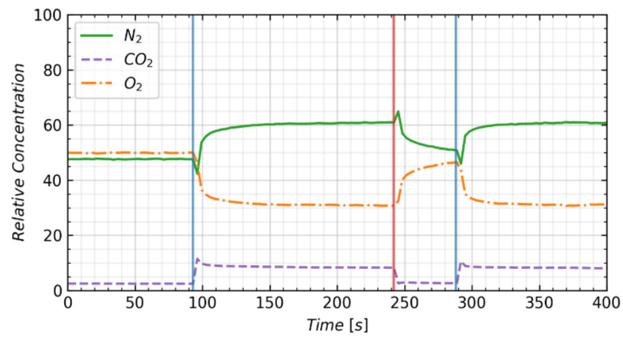

Figure 7: RGA monitoring during the M1 commissioning phase. The blue lines indicate the shutter opening, the red its closure. N_2 was monitored as it has the same atomic mass of carbon monoxide, changes on its concentration indicates that we were indeed monitoring CO on our experiment.

CONCLUSION

The SABIA M1 exactly constrained, high heat absorbent mirror was designed, assembled, and commissioned in 2023. The challenge on this design was to combine an internal water-cooled mirror with precision engineering concepts. Using a combination stiff actuator and FLS we developed a highly linear and stable mechanism. To protect both vacuum levels and electronics used, a vacuum guard was designed to encapsulate the water hoses used to cool the mirror down during operation.

As it is complex to determine the water flow induced vibration contribution on stability on the water hoses, tests were performed. It shows that water flow is responsible on over 35% of the instabilities. Yet this represent only 2nm increase on linear instabilities, when converted to rotation it is about 49nrad.

By using a partial pressure of oxygen gas onto the vacuum chamber we observed possible reactions with carbon-based structures on an attempt to prolong the mirror lifetime, but we need more testing to be certain. In the forthcoming months the SABIA beamline shall end its technical commissioning and entered the scientific commissioning.

ACKNOWLEDGEMENTS

The authors would like to gratefully acknowledge the funding by the Brazilian Ministry of Science, Technology and Innovation, the contributions of the LNLS team and partners.

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