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INSTALLATION AND COMMISSIONING OF THE EXACTLY-CONSTRAINED X-RAY MIRROR SYSTEMS FOR SIRIUS/LNLS

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Abstract

Innovative exactly-constrained thermo-mechanical designs for beamline X-ray mirrors have been developed since 2017 at the 4th-generation Sirius Light Source at the Brazilian Synchrotron Light Laboratory (LNLS). Due to the specific optical layouts of the beamlines, multiple systems cover a broad range of characteristics, including: power management from a few tens of mW to tens of W, via passive room-temperature operation, water cooling or indirect cryocooling using copper braids; mirror sizes ranging from 50 mm to more than 500 mm; mirrors with single or multiple optical stripes, with and without coatings; and internal mechanics with one or two degrees of freedom for optimized compromise between alignment features, with sub-100-nrad resolution, and high dynamic performance, with first resonances typically above 150 Hz. Currently, nearly a dozen of these in-house mirror systems is operational or in commissioning at 5 beamlines at Sirius: MANACÁ, CATERETÊ, CARNAÚBA, EMA and IPÊ, whereas a few more are expected by the end of 2021 with the next set of the forthcoming beamlines. This work highlights some of the design variations and describes in detail the workflow and the lessons learned in the installation of these systems, including: modal and motion validations, as well as cleaning, assembling, transportation, metrology, fiducialization, alignment, baking and cooling. Finally, commissioning results are shown for dynamic and thermal stabilities, and for optical performances.

INTRODUCTION

For the past couple of years many beamlines have passed from the design stage to assembly, installation, and commissioning at the 4th-generation Sirius Light Source at the Brazilian Synchrotron Light Laboratory (LNLS) [1]. Regarding the novel exactly-constrained X-ray mirrors for Sirius [2], during the design phase extra care was taken to ensure beam characteristics – i.e., acceptable nanometric deformation into the mirror's optical faces –, and alignment capabilities at the beamline, with new procedures, tools, and manuals being developed to certify installations.

Five beamlines at Sirius, namely, MANACÁ (MAN), CATERETÊ (CAT), CARNAÚBA (CNB), EMA and IPÊ, summarized in Table 1, currently rely on these in-house solutions, and a few more are expected by 2021. Through the commissioning phase on the first three of them, some important results have been found regarding fine and coarse alignment, leading to some significant beam results. Thermal management and cryogenics, modal and bench stability results are briefly presented. Some potential future improvements were found and are briefly discussed.

Table 1: First Beamlines Summary

Beam-line	Energy Range	Source	Status
CNB	2.05–15 keV	ID	Commissioning
MAN	5–20 keV	ID	Commissioning
CAT	5–20 keV	ID	Commissioning
IPÊ	100–2000 eV	ID	Installation
EMA	2.7-30 keV	ID	Assembling

ASSEMBLY AND INSTALLATION

Following standardized step-by-step guidelines, internal mechanisms pre-assembly, characterization and fiducialization ensures high-quality and repeatability to the assembly and installation processes. The main procedures steps are presented and discussed.

Assembly

A well-done cleaning certifies the removal of any contaminants into the ultra-high vacuum (UHV), to which most of the mirror systems are submitted. The main contaminants identified are machine oil used for lubrication, human skin oil, dust, and metal particles from machining which are mainly encountered on surface roughness and holes.

The first cleaning process is mechanically pre-cleaning the parts using the alkaline detergent IC115 which is followed by common water and demineralized water rinsing. To guarantee the part cleanliness, when necessary, an ultrasonic bath with the part submerged into a IC115 (10%) and water solution at ambient temperature is made for variable times, depending on the part size, geometrical complexity, and material.

A comprehensive and intuitive pre-assembly workflow has been developed ensuring quality and repeatability. The internal mechanism assembly method can be subcategorized into some main stages and were executed inside a controlled clean room [3]. Firstly, the mirror support is fixated, securing position, and favoring the precision mechanism fixation. Then, dowel pins and folded leaf-springs (FLS) fixation can be done (see [2]). The pins guarantee positions according to design. All FLS need to be screwed by hand before tightening, to prevent pre-tensioning, which might induce asymmetric stiffness into the system. Numer-

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ous assembly tools have been developed to certify positioning and alignment of the stiffness components between the mirror and the mirror support. Lastly, sensors and actuators can be assembled, which include temperature sensors and heaters, for temperature measurement and control; linear encoders, for the support position measurements; and the piezo walker for fine movement actuation. All cables need to be divided, sorted, and routed on the top of the base frame. Figure 1 shows the CAT M2 mirror internal mechanism before the mirror was mounted to it.

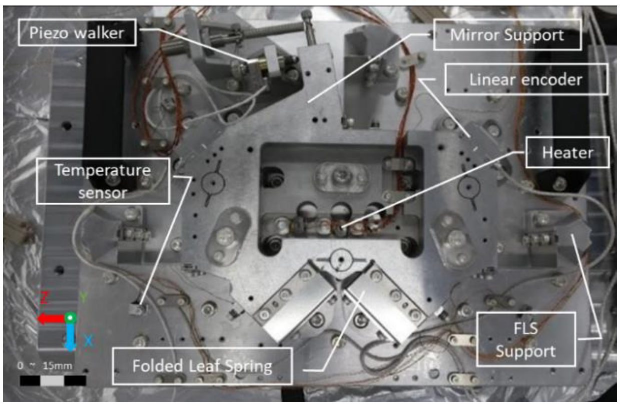

Figure 1: Fully assembled CAT M2 internal mechanism.

Fiducialization

An indirect fiducialization procedure has been developed to virtually match the components of interest from two independent measurement setups. The mirrors substrates are measured using a high-precision CMM (coordinate measuring machine) (Hexagon Global Performance). In turn, the assembled internal mechanics, that finally defines de mirrors positions, are measured using an articulated measuring arm (7-axis ROMER by Hexagon). The accuracy and repeatability of this procedure is below 0.1 mm, in average. As illustrated in Fig. 2, four fiducialization points outside the UHV chamber are also measured, to be related to the Sirius metrology network during the alignment campaigns with laser trackers [4].

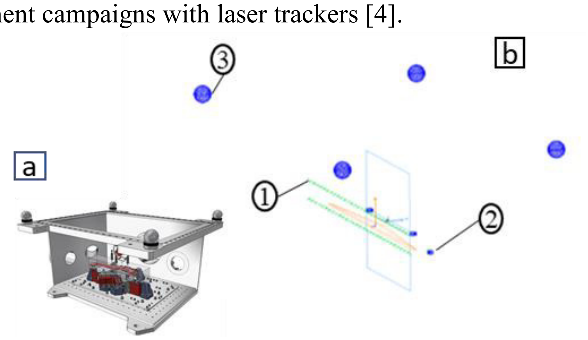

Figure 2: (a) CAT M2 CAD representation and (b) CAT M2 internal mechanism fiducialization measurements: (1) mirror optical face, (2) mirror internal mechanism, and (3) fiducialization points.

Installation

Following the offline internal mechanisms assembly, the installation procedure at the beamline starts by isolating the optical hutch, installing an auxiliary portable laminar flow close to it, and iteratively cleaning both ambients until particle level measurements reach class ISO 5. First, the internal mechanisms without the mirrors are mounted to the vessels on the granite benches under the laminar flow, as depicted in Fig. 3. Then, the vessel is covered and transported with the laminar flow to inside the hutch, with controlled temperature of 24 ± 0,1 °C. Once everything is settled, the vessels are reopened, and the mirrors are mounted on the internal mechanisms.

Figure 3: CAT M2 granite bench and UHV chamber inside a portable cleanroom laminar flow ready for the installation procedure.

Due to higher thermal loads, some of the optical systems must be actively cooled. The strategy varies depending on beam aspects and deformation budgets [5], but all share the concept of flexible copper braids as heat conductors to couple the optics to the thermal sinks [6]. Depending on the constraints of the design, the fixation of the braid to the mirrors is done before or after the attachment of the mirror on the support (see Fig. 4). In the first case, the mirror is carefully manually hold, with is its optical face facing slightly downwards for the braid attachment to avoid particles contamination on the optical face, then, the fixation on the supporting frame is performed. In the latter, the mirror is already safely mounted to its support when the braids are connected. The last step is the cryostats fixation and UHV chamber closure. The UHV chamber seal is certified doing a standard leak test using helium gas.

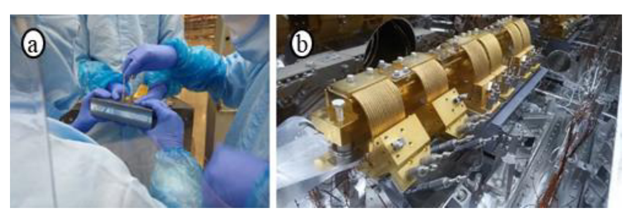

Figure 4: (a) CAT M1 flexible copper braid being fixed to the mirror and (b) the CAR M1 assembly installed inside the UHV chamber.

Baking

Depending on substrate, coating, and beam characteristics, as well as the operational energy range, X-ray mirrors may require UHV to XHV (ultra-high vacuum and extreme ultra-high vacuum) conditions to avoid the contamination and degradation of the optical surface. This is true especially for cryogenic systems, in which the gas molecules

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become more strongly attached to the cold surfaces. To reach this environment, it is required to bake out the chamber with all the mechanics, motor, encoders, and X-ray mirror, such that desorbed water and other undesired elements can be pumped out.

Having the maximum baking temperature limited by the piezo actuators, all subsystems are baked at 80 ± 0.2 °C for about two weeks. Temperature homogeneity and stability is reached by using a "baking tent" with temperature control, as illustrated in Fig. 5. The final pressures of all systems are in the order of low 10^{-10} mbar.

Figure 5: Setup of the "baking tent" used at the beamline, developed to avoid high temperatures outside the tent.

COMMISSIONING

First results regarding alignment, vibrations, and thermal control have been obtained during commissioning of the first systems. Concerning the Sirius beamlines optical layout, the standard concept for high stability is the use of side-bounce sagittal cylindrical mirrors with fixed shape to deflect and focus the beam [7]. Figure 6 shows the beam focalized by the M1 mirror at the Secondary Source Aperture (SSA) at the CNB beamline, with a full width at half maximum (FWHM) value of about 45 µm [8].

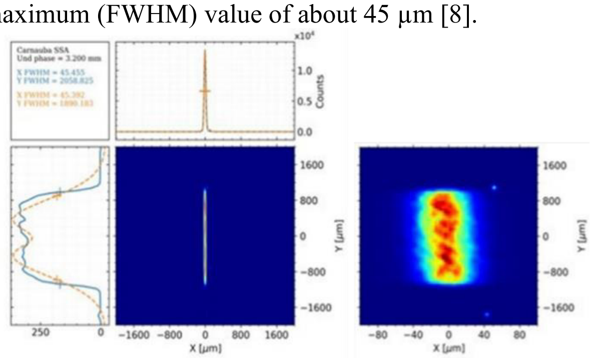

Figure 6: Measurement for the horizontally-focused beam at the CNB beamline, producing a vertical-line beam.

Regarding modal results, measurements performed on M1 and M2 CNB mirror systems have shown that first resonances in the bench are related to the ionic pump decoupling from the bench at approximately 42 Hz for both mirrors (see [2]). Yet, as these components represent only 10% of this systems mass, the granite modes are higher, and the vacuum chambers and mirrors have even higher suspension with respect to the bench (148Hz for M1 and 130Hz for M2), no amplification issues should occur. Stability on the benches and surrounding floor measurements have been done to complement the modal information [9]. An example is given in Fig. 7 for the horizontal displacement of the granite benches of M1 and M2 at CNB, which can be integrated to find displacements in order of about 10 nm.

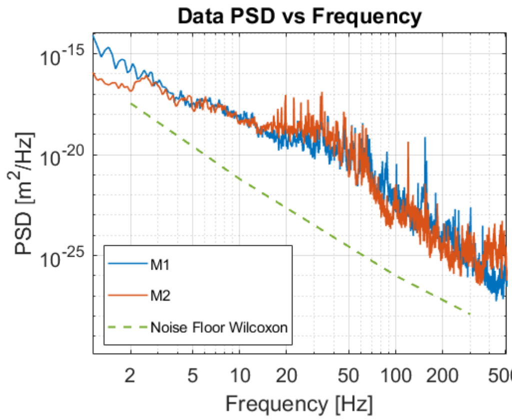

Figure 7: Horizontal displacement Power Spectrum Density measurements for CNB M1 and M2.

As for thermal management, the systems had been modeled using both FEA in ANSYS® and lumped mass in MATLAB®, in which PID control tuning could also be implemented [10]. In practice, to ensure temperature stability, minimizing deformation and drift in the optics, an in-house low-cost cryocooling solution was developed together with a high-performance temperature control architecture [11]. An example is given in Fig. 8 for the CAT M1, with temperature stability around 2 mK range over several hours.

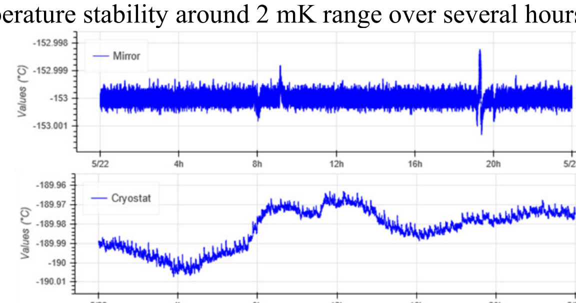

Figure 8: CAT M1 temperature deviation, with maximum values of about 2 mK.

CONCLUSION

The successful assembly, installation, and preliminary commissioning of the novel Sirius mirrors systems at the MANACÁ, CARNAÚBA and CATERETÊ beamline validated the proposed innovative concept and the required procedures. Indeed, specific tools and strategies have been developed for cleaning, baking, and assembly, according to the final alignment, dynamics, and figure preservation targets. These first results will feedback the design of the new systems to come, whereas more tests are planned for the granite benches ranges, repeatability, and accuracy.

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