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THE STATUS OF THE HIGH-DYNAMIC DCM-Lite FOR SIRIUS/LNLS

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Abstract

Two new High-Dynamic Double Crystal Monochromators (HD-DCM-Lite) are under installation for QUATI (superbend) and SAPUCAIA (undulator) beamlines at Sirius. The HD-DCM-Lite portrays an updated version of Sirius LNLS HD-DCMs not only in terms of being a lighter equipment for sinusoidal scans speeds with even higher stability goals, but also bringing forward greater robustness for Sirius monochromators projects. It takes advantage of the experience gained from assembly and operation of the previous versions during the last years considering several work fronts, from the mechanics of the bench and cooling systems to FMEA, alignment procedures and control upgrades. In this work, those challenges are depicted, and first offline results regarding thermal and dynamical aspects are presented.

INTRODUCTION

In recent years, LNLS has successfully developed and operated a cutting-edge high dynamic double crystal monochromator (HD-DCM) tailored for 4th generation light sources, representing a significant leap forward in terms of mechanical design and control. This innovation has yielded a state-of-the-art product, distinguished by its stability, both for fixed-energy and scan work [1–3]. The success of the first units in MANACA and EMA beamlines has driven the design of two new units, containing improvements designed [4] and assembled entirely by the LNLS team. Such enhancements focused on enabling high-speed sinusoidal scans capabilities [5] as required by QUATI [6], adapting to the energy range of the new beamlines (QUATI and SAPUCAIA), increasing stiffness, implementing control and FPGA optimizations [7], and applying Design for Manufacturing and assembly (DFMA) techniques to minimize the efforts required during mounting and offline commissioning phases.

Figure 1 shows the complete system's in-vacuum parts, highlighting its subcomponents, namely: the granite bench (GRA) (1); the goniometers rotary stages (ROT) (2) with their cooling systems; the goniometer frame (GOF) (3) for the crystal module mounting; the first crystals (CR1) (6), Si(311) and Si(111), which are fixed on the Metrology Frame 1 (MF1) (5), where the interferometer mirrors (IFM) are placed; the Auxiliar Frame 1 (AF1) (4), supporting the MF1; and the ShortStroke (SHS) (8), for mounting the second crystals (CR2) (7), elastically connected to the Short Stroke Frame (SSF) (9). The lower image offers an upstream view of the monochromator, showcasing the Upstream Mask (10) and the Cryogenic Pump (11). For a more detailed and functional explanation, please refer to [4].

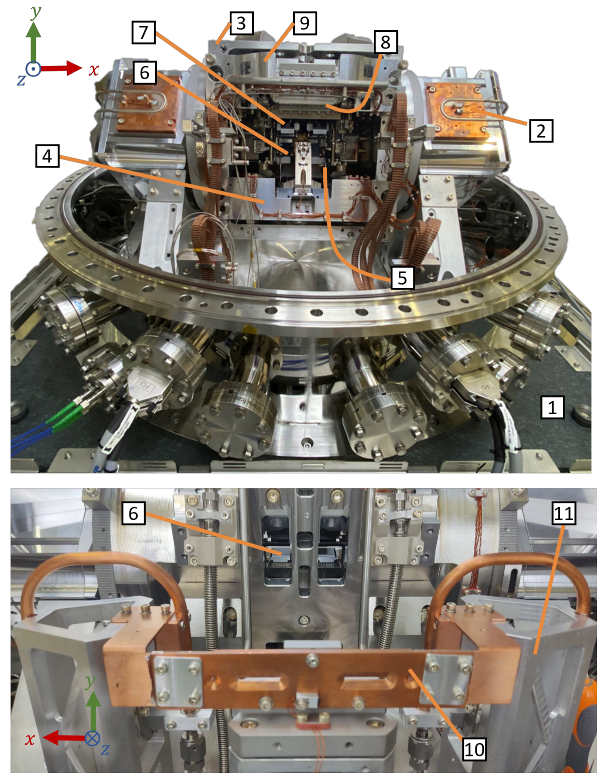

Figure 1: Overview of the assembled SAPUCAIA's HD-DCM-Lite with annotated subparts.

KEY DESIGN MODIFICATIONS

Drawing upon the insights gleaned from the design, assembly, and commissioning of previous HD-DCMs, we have implemented several design updates with the goals of enhancing performance, streamlining the production process, and facilitating the assembly phase. For example, we attest that improvements in the granite base, such as new routing parts, equipment protection components, and features designed to facilitate the placement of feet during assembly, played pivotal roles in the the assembly phase. Specific details regarding some updates will be elaborated upon in the subsequent subsections.

Rotary Stages

To meet the requirements of the QUATI (quick-EXAFS) beamline, a redesign of the rotary stage system was necessary. In addition to doubling the number of actuators to achieve extended scanning speeds, scans of longer duration required the implementation of a specialized thermal solution. This solution took the form of a water cooling system using machined copper components, as illustrated in Figure 1 under item (2).

The use of two mechanically coupled rotary stages intro-

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duces a synchronization challenge. To address this issue, we separately identified each goniometer plant and implemented a closed-loop gantry system to control both. For more comprehensive information, refer to [7].

Furthermore, goniometers are intricate systems that may contain contaminants capable of impeding ultra-high vacuum (UHV) processes. A straightforward method to optimize the overall baking time for the monochromator system involves baking the goniometers separately in a dedicated vacuum chamber while the core components of the system are still in the assembly phase. This approach also helps prevent the rotary stages from contaminating the DCM's vacuum chamber.

Alignment

We replaced the C01 interferometer with the F04 model from SmarAct [8], extending the operating range, simplifying alignment, and enabling in-house self-testing. Previously, this test required specialized equipment and was only feasible during initial assembly. It involves rotating the SHS to its angular End of Stroke (EoS), ensuring clearance in the voice coil's axial direction. Figure 2 displays test results, with ranges up to 15 mrad measured by the interferometer.

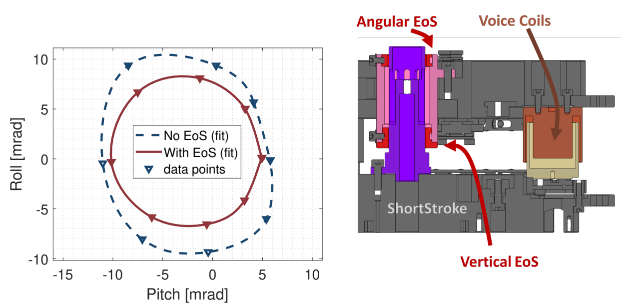

Figure 2: Angular limits on pitch and roll with and without the EoS (left), along with a CAD image (right) illustrating the physical components involved.

However, these new interferometers have uncollimated beams, causing signal quality variations with head-to-mirror distance. System self-adjustment is required at a specific position for optimized readings across the entire vertical range.

Interferometers also presented challenges in crystalline plane alignment. Even from reputable suppliers, silicon crystals often exhibited miscut errors around 2 mrad. Our goal was to achieve total parallelism below 250 µrad to maximize displacement ranges and streamline commissioning. XRD measurements and machining of mounting pads determined the expected parallelism, detailed in Table 1.

LN2 Cooling Circuit

The liquid nitrogen cooling circuit comprises the following subsystems: the cryocooler and its hoses, and, inside the vacuum chamber: the cryogenic pump, the manifold with cooling blocks, and the hoses connecting them. The design of the cryogenic pump remained as originally planned, with

Table 1: Expected Relative Alignment to Correct Mismatch μ Between Inter-Crystalline Planes Before and After Corrections

Crystal pair		Before [µrad]		After [µrad]	
Beamline	**Orientation**	μ_{pitch}	μ_{roll}	μ_{pitch}	μ_{roll}
SPU	Si(111)	-1185	374	-43	-207
SPU	Si(311)	1849	-875	99	93
QUA	Si(111)	-171	1032	-210	58
QUA	Si(311)	456	56	-206	2

a geometric difference from previous units to facilitate access to other components while retaining the use of a copper tube brazed to standard VCR fittings. The flexible hoses from previous units were retained after fatigue testing and as their torque within a 40° range remained well below actuator limits. The manufacturing process for the manifold, detailed in [9], stands out as the most labor-intensive. The order of certain processes was altered due to the risks associated with concurrent brazing in multiple regions as the final step, including potential leaks or channel blockages. Therefore, it was decided to make the laser welding between capillary tubes and stainless steel inserts the final step in the process.

IN-POSITION AND SCANNING PRELIMINARY RESULTS

The system's identified plant closely mirrors the model, also exhibiting minimal cross-talk, which simplifies the task of developing an appropriate controller [7]. The offline stability results (RMS) are as follows: the gap below 1 nm; pitch and roll around 7 and 8 nrad, respectively; while Bragg is within the encoder count of 191 nrad. Notably, all results meet the designed specifications [5]. The pitch performance, while not consistently reaching the expected 5 nrad yet, still outperforms previous state-of-the-art HD-DCM units. Figure 3 compares HD-DCM-Lite's experimental validation with the HD-DCM, and their respective models for pitch parallelism.

Introducing new challenges in fly-scan perspectives, synchronization is crucial. Doubling the number of Bragg actuators, while simultaneously reducing inertia by a factor of 6, presents a promising outlook for rapid scanning. Figure 3 (b) illustrates an example scan with its respective error in synchronism between rotary stages. While fly-scan results remain preliminary, high amplitude in mid-frequencies and high frequencies with low amplitudes have been reached. Further studies on current control are now in place, in order to optimize the rotary stages torque output, further extending the scanning capabilities.

THERMAL MANAGEMENT

In addition to maintaining components within their respective operating temperature ranges, the primary goal of HD-DCM-Lite's thermal management is to ensure that CR2 maintains the same d-spacing as CR1 (see [4, 10]).

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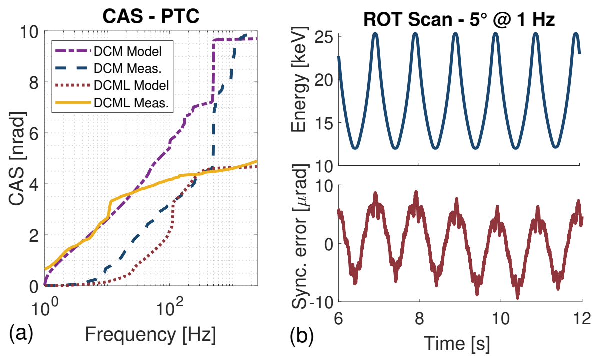

Figure 3: Performance results: (a) Pitch stability Cumulative Amplitude Spectrum (courtesy data from [3]), and (b) Fly-scan example: 5° amplitude at 1 Hz frequency.

Given the HD-DCM's design principle of decoupling the crystal pair's movement, it's crucial to maintain a thermo-mechanical balance. The dynamical model assumes negligible braid stiffness. However, the initial thermal design incorporated smaller copper braids as a safety margin, introducing unwanted stiffness between the first and second crystal modules.

This issue prompted the exploration of two primary approaches for resolution. First, with the physical braids in hand, we sought to experimentally characterize their effective thermal conductivity, enabling more precise estimates of the ideal braid length. Second, by analyzing the dependence of stiffness on the mounting geometry, we aimed to optimize the braid configuration. Figure 4 illustrates a comparison between an 'S' and a 'C' braid configuration.

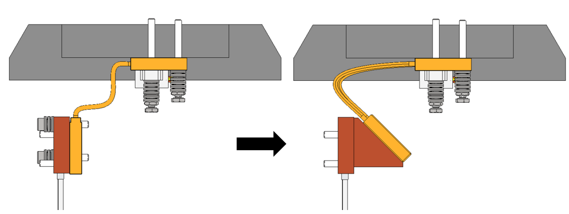

Figure 4: Braid configurations: in 'S', on the left and, 'C', on the right.

As illustrated in the figure, an intermediate triangular copper component was necessary to enable the assembly of the braid's end at the desired angle.

By adopting the 'C' configuration with a 55 mm braid, we achieved both high mechanical decoupling and the ideal temperature for the second crystal. It's crucial to highlight, however, that achieving the desired dynamic outcome heavily relies on the assembly process. This process requires meticulous attention to create specific braid conformations that optimize decoupling while ensuring no components obstruct the beam path. The final temperatures and expected values are detailed in Figure 5.

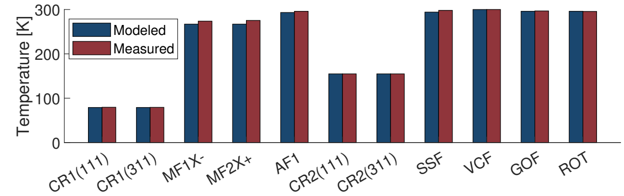

Figure 5: Final temperatures of the system and comparison with expected values.

FMEA

The DCM is pivotal for beamline instrumentation, impacting efficiency and research accuracy. Calibration, alignment, dynamics, and internal conditions must be precise. We employ Failure and Effects Mode Analysis (FMEA) for systematic design fitness evaluation.

Adopting FMEA enhances project quality and reliability via a '7-Step' approach, deepening system understanding, and prioritizing actions based on failure severity, prediction, and detectability. Optimizing this process entails integrating risk assessment with early-stage design. A Baseline FMEA is intended for future projects. Consistent information flow is crucial as complexity increases.

Preventive and detective controls were introduced, including reviews during design, manufacturing, and assembly. Enhanced monitoring and interlocking signals mitigate motion and chamber environment issues.

After multidisciplinary meetings, teams were assigned to implement improvements. The control team safeguards system integrity, while the automation team uses transducer data for environmental monitoring. Optics and Design teams develop tests based on previous experiences to meet specifications. Overall, this initiative fosters better knowledge sharing across teams, enhancing design, documentation, and support.

NEXT STEPS

The SAPUCAIA's unit is currently undergoing offline commissioning and is being prepared for vacuum procedures and it's expected to undergo online commissioning in the start of 2024. Meanwhile, QUATI's HD-DCM-Lite is still finishing in the assembly phase, with offline commissioning expected to start also at the start of 2024.

CONCLUSION

Key design modifications have streamlined assembly and boosted performance. In-position and scanning results meet specifications, showing great promise for fly-scan capabilities. Effective thermal management has been achieved, and FMEA has enhanced system reliability. These advancements demonstrate LNLS's commitment to advancing synchrotron technology.

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