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COMMISSIONING AND PROSPECTS OF THE HIGH-DYNAMIC DCMs AT SIRIUS/LNLS

R. R. Geraldes†[1], J. L. Brito Neto, R. M. Caliari, G. S. de Albuquerque, M. A. S. Eleotério, S. A. L. Luiz, M. A. L. Moraes, A. V. Perna, M. Saveri Silva
Brazilian Synchrotron Light Laboratory (LNLS), 13083-970, Campinas, São Paulo, Brazil
[1]also at the Eindhoven University of Technology (TUe), 5612AZ Eindhoven, The Netherlands

Abstract

The High-Dynamic Double-Crystal Monochromator (HD-DCM) is an opto-mechatronic system with unique architecture, and deep paradigm changes as compared to traditional beamline monochromators. Aiming at unmatching scanning possibilities and positioning stability in vertical-bounce DCMs, it has been developed since 2015 for hard X-ray beamlines of Sirius Light Source at the Brazilian Synchrotron Light Laboratory (LNLS). Two units are currently operational at the MANACÁ (macromolecular crystallography) and EMA (extreme conditions) undulator beamlines, whereas a model for extended scanning capabilities, the so-called HD-DCM-Lite, is in advanced development stage for forthcoming bending magnet and undulator beamlines. This work presents commissioning data related to the two HD-DCM units, together with the developed operation strategies and the overall control architecture, with emphasis on the 10 nrad RMS (1 Hz to 2.5 kHz) pitch parallelism performance, the calibration procedures and flyscan-related discussions.

INTRODUCTION

The High-Dynamic Double-Crystal Monochromator (HD-DCM) [1] has been developed by the Brazilian Synchrotron (LNLS) for Sirius [2] and the demanding new generation of X-ray beamlines. With a predictive design methodology [3] and original concepts for a DCM that are based on precision mechatronics [4], it has proven to meet the mark of 10 nrad RMS pitch parallelism performance, both in fixed-energy and scanning operation modes, over the broad frequency range from 1 Hz to 2.5 kHz, which is sui generis in vertical-bounce DCMs.

The system has already been described to the community in different aspects: the conceptual design, the mechatronic principles and thermal management solutions were presented in MEDSI 2016 [5–8]; results of in-air validation of the core, together with system identification and control techniques in the prototyping hardware, were shown in ICALEPCS 2017 [9, 10]; the offline performance of the full in-vacuum cryocooled system, including scans solutions were presented in MEDSI 2018 [11]; and the dynamic modelling work, together with updated control design and the FPGA implementation in the final NI CompactRIO (cRIO) hardware were discussed in the ASPE Topical Meeting 2020 [12–14]. Here, commissioning results of the two operational units at MANACÁ and EMA undulator beamlines at Sirius are presented, together with procedures, strategies, and the related beamline architecture.

COMMISSIONING PROCEDURE

The commissioning procedure that has been developed for the HD-DCM follows the steps presented in Fig. 1 and described below:

1. *Beam through* consists of passing the first monochromatic beam of a given energy to downstream sensors or visualization elements after short scans in the Bragg angle, in the pitch angle of the 2nd crystal of the DCM and/or the undulator phase, which is a quick job if offline fiducialization and laser-tracker-based alignment procedures at the beamline are properly realized.
2. *Preliminary DCM-undulator tuning* is meant as a coarse mapping between the Bragg angle and undulator phase for different harmonics, which relies on beam simulation and can be done in terms of output flux or image processing.
3. *Preliminary Rocking Curve analysis* is related to optimizing the roll parallelism and scanning the pitch of the 2nd crystal in the DCM for a few energy values of interest. Thus, the quality of the crystalline lattice –which depends on manufacturing, mounting and the cryogenic thermal management – can be verified, while the internal metrology feedback to keep the parallelism according to maximum flux is evaluated.
4. *Preliminary energy calibration* is dedicated to calibrating the Bragg angle encoder homing offset according to one or more absolute energy values provided absorption standards in spectroscopy measurements.
5. *Fine DCM-undulator tuning* is the refinement of the undulator energy-phase calibration with the calibrated Bragg angles over the whole operational energy range.
6. *Fine energy calibration* consists in optionally exploring multiple absorption edges over the full energy range to calibrate occasional repeatable non-linearities in the encoder of the Bragg angle.
7. *Fine parallelism calibration* is an optional flux-based step for repeatable non-linearities in pitch (in the piston-tip-tilt internal metrology of the crystal cage, as described in [5]) as the gap between crystals varies over the full energy range.
8. *Fixed-exit calibration* is the final step in which angular or translational deviations of the monochromatic beam are mapped over the complete energy range by image processing, quadrant sensors or knife-edge measurements, and compensated by the internal degrees-of-freedom in the crystal cage.

† renan.geraldes@lnls.br

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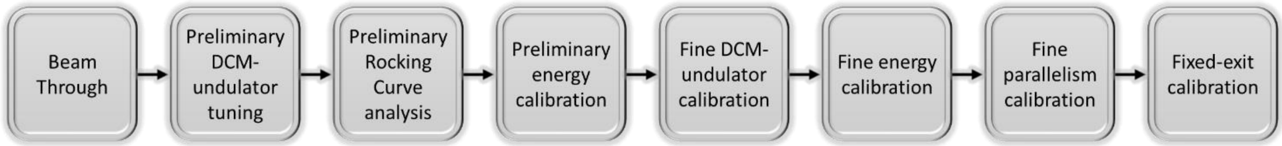

Figure 1: Commissioning procedure developed for the HD-DCM at MANACÁ and EMA undulator beamlines at Sirius.

Considering that ordinary calibration based on look-up tables would be incompatible with flyscan because of smoothness and differentiation issues, together with high-rate constraints, all the relations among quantities, i.e., energy, phase, angles and linear displacements, are defined according to polynomials, which are computed in real time at the FPGA level. Nominal, full-range calibration or short-range optimized polynomial sets can be defined. This process is repeated for both Si(111) and Si(311) crystal sets in the HD-DCM to provide a highly-stable monochromatic beam that can be explored in fixed-energy, step-scan and flyscan operation modes. The following section describes the integration architecture at MANACÁ as a case study.

INTEGRATION ARCHITECTURE

The HD-DCM has been designed not only to achieve position stability at fixed energy, but also to simultaneously enable high-performance spectroscopy in flyscan, which asks for consistent requirements for instrumentation and the control architecture at the beamline level.

Figure 2 depicts the integration diagram for MANACÁ. Information of the electron beam stability in the storage ring (SR) is made available to the beamline from two beam position monitors (BPMs), with synchronization triggers via an event handler hardware (EVE) developed in-house by the GCA group [15]. Regarding the undulator (UND) source, the options are still somewhat limited. Indeed, working in a coupled mode, the HD-DCM can currently only be used as the follower, receiving the quadrature signal that is derived from the undulator encoder. Furthermore, the trajectory generation in the Kyma commissioning undulator cannot be optimized for the best performance in flyscan with the existing firmware in its programmable logic controller (PLC) either. With the installation of the Delta undulator that has been developed in-house, a more extensive integration will be possible.

In addition to the HD-DCM, two focalizing mirrors (M1 and M2) compose the beamline optics, currently delivering a monochromatic beam of about 10x10 µm^2 at the sample position. After the M1, there is a component for diagnostics that contains an AXUV36 photodiode (PD) and a CCD-based beam visualization system (BVS) with a resolution of about 10 µm. The first is used for measurements of the Rocking Curves and for the *flux-based DCM-undulator tuning*. The latter is used for the *beam-through* step and visual inspection of the undulator emission profile when the M1 is removed from the beam path, but also to guide the alignment of the M1. After the M2, two Cividec diamond quadrant photon beam position monitors (XBPMs) are used for alignment, including the *fixed-energy calibration*, and beam stability measurements. A variety of in-vacuum filters are intended basically to control the flux at the sample, but have also been used as absorption standards for *energy calibration*. Finally, at the sample position the most common setup during commis-sioning consists in a YAG-Ce crystal and a high-resolution CCD-based optical microscope, which is used for the alignment of the mirrors, but also for *fixed-exit calibration* via image processing. Other items at the beamline are omitted in the diagram for clarity.

NI cRIO has been chosen as the standard controller for Sirius beamlines, being used not only to handle digital and analog signals of a variety of devices in rates up to 10 MHz, but also to host entire applications, as the HD-DCM itself, which runs at the control rate of 20 kHz. A special module, known as *time and trigger unit* (TATU), has been developed in-house by the SOL group for the NI-9401 board to work as a synchronization unit in the microsecond range.

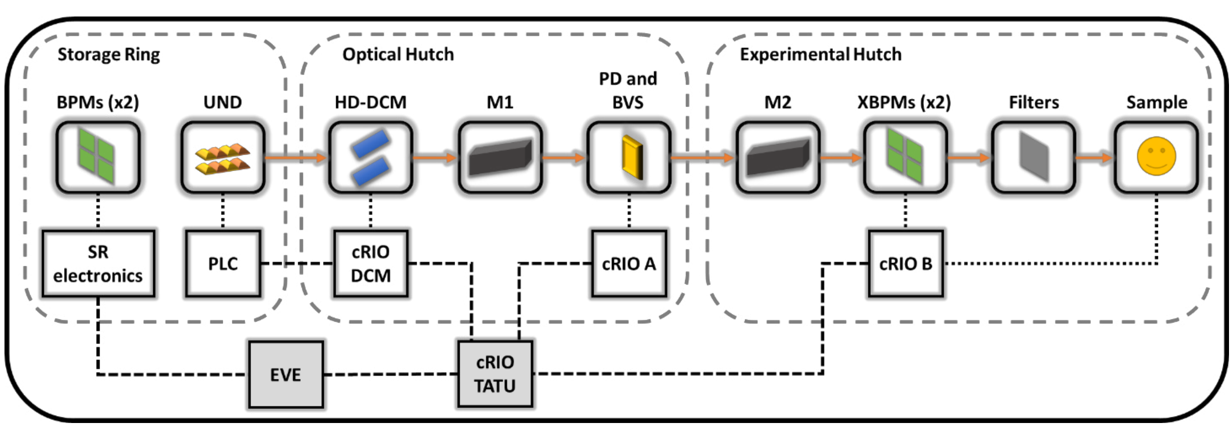

Figure 2: Integration diagram for the HD-DCM at MANACÁ beamline at Sirius. (Details in the text.)

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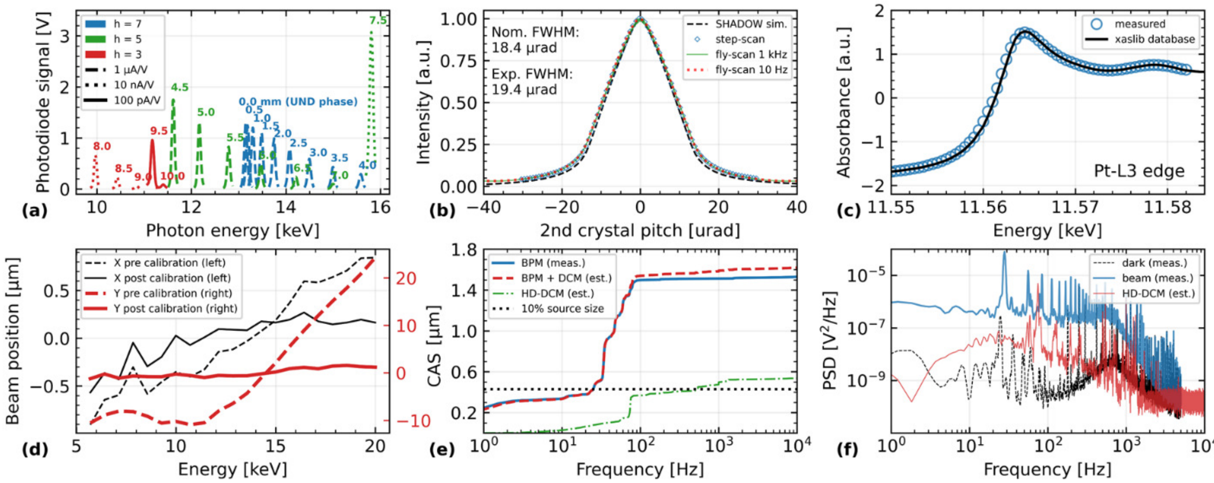

Figure 3: Commissioning results of the HD-DCM at MANACÁ and EMA beamlines at Sirius. (Details in the text.)

Thus, with the instruments relying on fast computing hardware and connected at the hardware level, commissioning and the experiments can be easily taken to the sub-millisecond range. Still at the FPGA level in cRIO, but with settings available to users at the EPICS level, averaging tools have been developed in-house to improve signal-to-noise ratio of digital and analog signals. The HD-DCM control itself is now fully available in EPICS via the Nheengatu solution developed by the SOL group to integrate EPICS with cRIO [16], and a library for the calibration procedures has been developed with Python scripts.

RESULTS

Figure 3 briefly illustrates some of the results obtained in the commissioning work of the HD-DCMs at MANACÁ and EMA beamlines. In (a), the photocurrent is measured (at different amplification gains) as a function of the photon energy for different undulator phases and harmonic tunings as the Bragg angle is scanned, such that the ideal tunings can be found and implemented a polynomial. In (b), measurements of the Rocking Curve for Si(111) at 20 keV are compared with theoretical simulated data, with agreement for the full width at half maximum within 5%. Step-scan data with detection averaging time of 1 s – and a total measurement time of about 5 minutes – is compared with flyscan data with detection averaging times of 1 ms (noisier) and 100 ms (smoother) – and total measurement time of 5 s each –, showing equivalent performance. In (c), the absorption edge for Pt at 11.56 keV is used for energy calibration at EMA. Although this measurement was done in step scan over a few minutes during calibration, up to 1 keV scans can also be realized in a few seconds in flyscan for spectroscopy experiments. In (d), the X and Y fixed-exit calibration via image processing at MANACÁ allowed the 10µm beam to have its vertical position dependence with energy reduced from more than 30 µm to less than 1µm over the full energy range available at the beamline, which was at the resolution and stability limits of the experimental setup. Thus, concerning accurate flyscan spectroscopy measurements, the largest possible continuous scan is only limited by the undulator characteristics. In (e), for stability evaluation, the estimated back-projected pitch stability of the HD-DCM at a given energy is compared via cumulative amplitude spectrum (CAS) with the vertical beam stability of the electron beam, as measured by the BPMs before the fast orbit feedback (FOFB) system is implemented in the SR. The DCM has a negligible impact in the vertical beam stability so far, which is confirmed in measurements with the XPBMs that are dominated by the source stability signature (not shown). Finally, in (f), a preliminary intensity measurement is shown also for stability evaluation. In this case, the 2nd crystal in the HD-DCM was intentionally detuned to the slope of the Rocking Curve for Si(333) at 20 keV, for the maximum flux-to-pitch sensitivity condition at MANACÁ. The power spectrum density (PSD) of the signal of the PD is shown in the dark condition for a noise background level and with beam on. The contribution of the HD-DCM could only be estimated from the internal metrology data, because over the whole range it would be partly noise-limited and partly overshadowed by the intensity variation of the source itself.

CONCLUSIONS

This work briefly summarizes the procedures, the integration architecture and some results in commissioning the HD-DCMs that at MANACÁ and EMA beamlines at Sirius. Thus, the innovative mechatronic architecture is now validated, allowing for superior beam position stability and enabling unmatching scanning possibilities, which can be explored both for higher throughput and new scientific opportunities. A new model for even faster scans, the so-called HD-DCM-Lite [17], is now in development.

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