CONTROL SYSTEM OF THE ForMAX BEAMLINE AT THE MAX IV SYNCHROTRON

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Abstract

This paper describes the design and implementation of the control system for the ForMAX beamline at the MAX IV synchrotron. MAX IV is a Swedish national laboratory that houses one of the brightest synchrotron light sources in the world, providing opportunities for cutting-edge research across a range of disciplines. ForMAX is one of the beamlines at MAX IV, designed for in-situ multiscale structural characterization from nanometer to millimeter length scales by combining full-field tomographic imaging, small- and wide-angle X-ray scattering, and scanning SWAXS imaging in a single instrument. To meet the specific demands of ForMAX, a new control system was developed using the TANGO Controls and Sardana frameworks. TANGO Controls provides a distributed control system that enables communication between devices and software, while Sardana is a Python-based software suite for controlling and coordinating data acquisition and processing. Using these frameworks allowed for the seamless integration of hardware and software, ensuring efficient and reliable beamline operation. The control system was designed to support a variety of experiments, including full-field tomographic imaging, small- and wide-angle X-ray scattering, and scanning SWAXS imaging. The system allows for precise control of the beam position, energy, intensity, and sample position. Furthermore, the system provides real-time feedback on the status of the experiments, allowing for adjustments to be made quickly and efficiently. In conclusion, the design and implementation of the control system for the ForMAX beamline at the MAX IV synchrotron has resulted in a highly flexible and efficient experimental station. TANGO Controls and Sardana have allowed for seamless integration of hardware and software, enabling precise and reliable control of the beamline for a wide range of experiments.

MAX IV AND FORMAX INTRODUCTION

MAX IV synchrotron [1], situated in Lund, Sweden, is a facility housing a 1.5 GeV storage ring and 3 GeV storage ring designed for the generation of highly brilliant X-ray synchrotron radiation. Employing state-of-the-art insertion devices and beamlines, MAX IV enables advanced studies across diverse scientific domains. The facility's beamlines are equipped with cutting-edge instrumentation to facilitate experiments in materials science, structural biology, chemistry, and physics. The synchrotron's operational parameters and advanced optics provide researchers with an exceptional toolset for probing materials at the atomic and molecular levels, fostering investigations into electronic structures, chemical processes, and intricate biological macromolecules. ForMAX, located at achromat 9 of the MAX IV 3 GeV ring, is a hard X-ray beamline focused on versatile structural characterization. With an emphasis on efficiency, the beamline seamlessly switches between full-field X-ray microtomography, small- and wide-angle X-ray scattering (SWAXS), and scanning SWAXS imaging. The microtomography provides non-destructive 3D mapping in the microscale range (1 µm to 5 mm), enabling studies such as porosity characterization in forest-based materials with a temporal resolution of 1 s. SWAXS explores nanoscale structures (1 to 500 nm) for understanding biobased nanomaterials with a temporal resolution in the ms regime. Scanning SWAXS imaging generates 2D or 3D images of fibril orientation within samples, but its temporal resolution is limited due to the potential need for ≈ 106 individual SWAXS images for 3D reconstruction.

FORMAX CONTROL SYSTEM

The control system governing the ForMAX beamline is a sophisticated infrastructure designed for precise and efficient experimental control. Making use of the TANGO Controls framework [2], it establishes a distributed architecture for seamless communication between diverse hardware components and software modules. Sardana [3], a Python-based software suite, assumes a pivotal role in orchestrating the control of ForMAX's instrumentation, ensuring streamlined data acquisition and processing. The integration of PandABox [4] augments system versatility, enabling adaptable control of diverse devices. IcePAPs, utilized as motor controllers, further amplify the system's capabilities, ensuring high-precision positioning and effective movement control. Taurus, Taranta and SVG synoptic are used for visualisation. The beamline synoptic panel is shown in Fig. 1.

Optics

ForMAX's optical components crucially manipulate x-ray beam parameters, utilizing a double multilayer mirror monochromator (MLM) with W/B4C and Ru/B4C layers, and a double-crystal Si (111) monochromator (DCM), both horizontally deflecting. Dynamically bendable Kirkpatrick-Baez mirrors provide beam control, complemented by four diagnostics modules with slits, radiation safety components, and beam viewers. The system incorporates dual monochromators, their activity governed by a global variable. Their distinct operational modes requires transitions managed via the `select_mono` macro. Monochromator energy is user-

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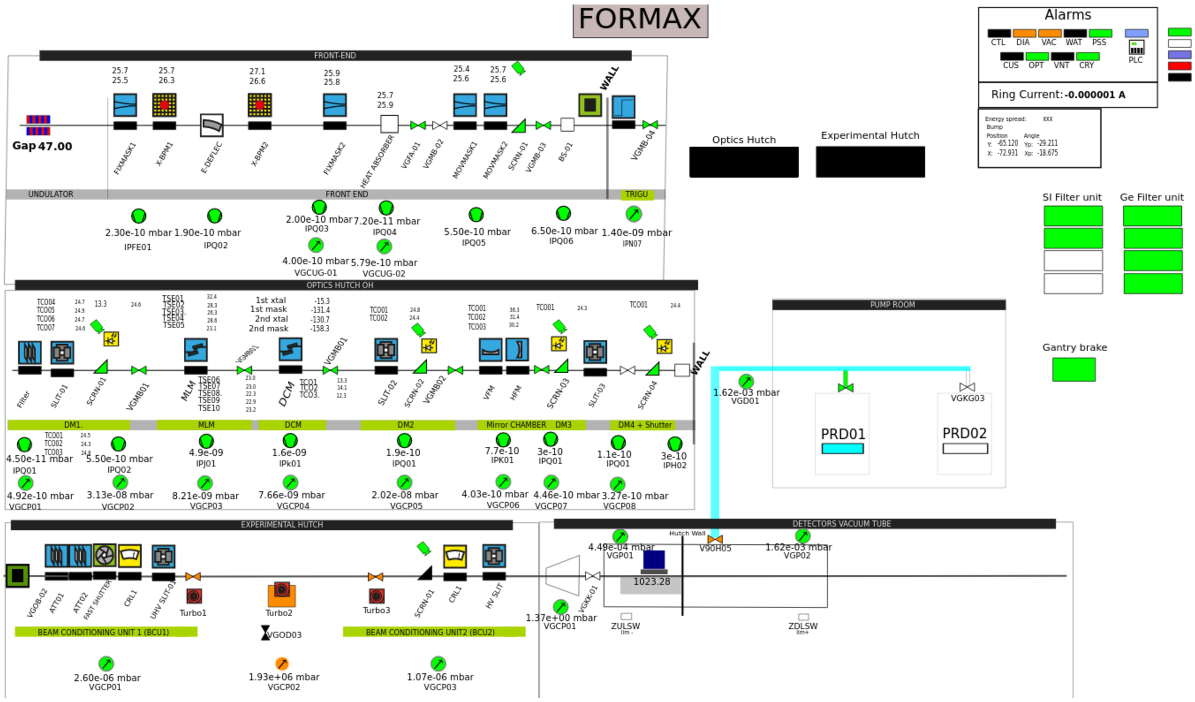

Figure 1: Synoptic panel of ForMAX.

regulated through `setE_DCM` and `setE_MLM` macros. The horizontally deflecting DCM utilizes a variable Bragg angle, which is pivotal for the selection and transmission of the desired photon energy, all while maintaining fixed inboard offsets. The DCM is robustly designed to handle heat loads of up to 80 W on the first crystal and incorporates liquid-N2-cooled copper plates for efficient indirect cooling. Furthermore, the design specifications of the DCM include a nominal inboard offset of 10 mm, with the apparatus operating efficiently within an energy range of 8–25 keV, utilizing Si(111) crystals. For experimental procedures that necessitate elevated levels of x-ray flux, a broadband monochromator positioned upstream feeds into the DCM. The `dcm_energy` pseudomotor moves the `dcm_bragg` motor to the correct Bragg angle based on Bragg's law, while the `dcm_offset` pseudomotor moves motors in order to achieve a target beam offset for the current `dcm_bragg` value. To move the DCM out of the beam for the experiments with the MLM one can use `park_dcm` macro. The horizontally deflecting MLM is analogous to the DCM in functionality but is distinctive in that it utilizes multilayer-coated Si substrates. The MLM is engineered with a long translation in the z-direction, which is essential for accommodating smaller Bragg angles, cooling multilayers, and substrates. The MLM is also characterized by coatings of `W/B4C` and `Ni/B4C`, with the selection of coatings being efficiently facilitated by the vertical translation parameter, `mlm_y`. The values associated with this parameter are -7 mm for W/B4C and 7 mm for Ru/B4C. The vertical translation of the MLM is achieved by the `mlm_y` pseudomotor, which moves proper motors to the same position. The same goes for the lateral translation and it's done by `mlm_x` pseudomotor. The main Bragg rotation is achieved by the `mlm_bragg` pseudomotor, and the `mlm_energy` moves the `mlm_bragg` to the correct Bragg angle based on Bragg's law. The `mlm_offset` is used to achieve a target beam offset for the current `mlm_bragg` value.

End Station

The ForMAX beamline is designed to amalgamate full-field X-ray microtomography, small- and wide-angle X-ray scattering (SWAXS), and scanning SWAXS imaging capabilities into a singular, integrated instrumentation. The end station of the beamline comprises multiple constituent components including: a duo of beam conditioning units, a configured sample table, a detector gantry, and a flight tube. The sample table includes one motorized stage facilitating x-axis movement and two motorized stages for y-axis movement. The breadboard's pitch is adjustable via the y-axis stages. The pseudomotor, labeled `tab_y`, enables vertical movement of the sample table by coordinating the y stages to move uniformly in the same direction and distance. The detector gantry offers flexibility for various experimental modes and detector changes. It features motorized z-axis movement. Both the tomography microscope and the WAXS detector will be mounted on this gantry. Each device will have x and y stages, allowing them to be moved into or out of the beam's path as needed. ForMAX has three modular stacks of sample stages, for tomography, standard SWAXS, and scanning SWAXS imaging.

The flight tube, measuring 9 meters in length, houses the SAXS detector positioned on a motorized XYZ stage. Detector's lengthy translation is managed by a specialized Sardana controller, which operates in the parametric trajectory mode of the IcePAP. This custom controller, while based on the standard Sardana IcePAP controller, overrides several methods to facilitate particular movements in the parametric trajectory mode.

Three motion modes are defined:

- In the tube's central section, fast motor movements are permitted, implementing a 1:1 ratio between physical and trajectory units. Therefore, a movement command issued at X units/s corresponds to a velocity of X mm/s.
- In the tube's central section, fast motor movements are permitted, implementing a 1:1 ratio between physical and trajectory units. Therefore, a movement command issued at X units/s corresponds to a velocity of X mm/s. The tube's proximal area allows only slow movements with a 1:N mapping from physical units to trajectory units, where N represents the speed ratio between the allowed maximum and minimum speeds. Consequently, a command at X units/s yields a movement at X/N mm/s.
- A transitional zone exists between the aforementioned areas, where motor speed gradually increases or decreases to prevent abrupt accelerations.

Detectors:

- Tomography: the full-field tomographic imaging detector will incorporate sCMOS cameras linked with an X-ray microscope. Two specific sCMOS camera models will be utilized: the Andor Zyla 5.5 and the Hamamatsu ORCA-Lightning, both coupled to the X-ray microscope.
- WAXS: the WAXS detector is the X-Spectrum LAMBDA 3M area detector. This detector features a distinctive "wind-mill" design, consisting of four detector modules.
- SAXS: for SAXS detection, the system employs the Dectris EIGER2 X 4M area detector.

Scans

At ForMAX, both step scans and continuous scans are supported. In a step scan, the motors move to specific points, stop at each point, and then data is collected for one or more channels. Only after the data collection is complete at one point do the motors move to the next point. In a continuous scan [5], the motors don't stop during data collection. Instead, data is gathered while the motors are still in motion. Continuous scans are usually used when one want to optimize data acquisition time by avoiding the delays associated with motor acceleration and deceleration between data points. In continuous scan setup at ForMAX, there is a scanning system that involves two motors. For each step of the second motor, the first motor scans continuously, effectively tracing out a grid pattern. The behavior of motor1 during the meshct scan is shown in Fig. 2.

To ensure synchronization during data acquisition, PandABox is used, which generates external trigger pulses. These triggers coordinate the data collection process and help ensure precise timing for our experiments. The PandABox schema is shown in Fig. 3.

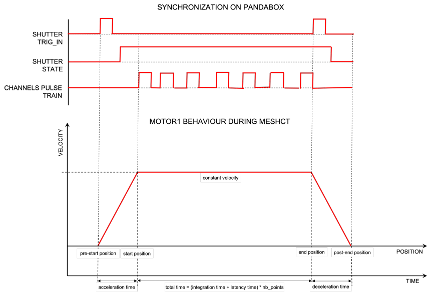

Figure 2: The behavior of motor1 during the meshct scan correlated with PandABox pulses synchronization.

For tomography experiments, a tomoscan macro has been developed. This macro is made up of three parts: a darkscan, a whitescan, and the tomoscan itself. The darkscan is a timescan where the shutter remains closed, while the whitescan is also a timescan, but with the shutter kept open. These two scans serve as preliminary macros before the actual tomography scan starts.

OPTIMIZING THE SCANS

While performing experiments, two problems with continuous scans were identified:

- the drifting issue,
- a overhead per line related to arming of detectors on each line of a scan.

The Drift Issue

The problem of drifting occurred because the PandABox sent an extra pulse for each line. This happened because of how Sardana calculates the velocity and the total time for the meshct scan. The drifting issue is visualised in Fig. 4. Sardana formulas:

$$velocity = \frac{position\_final - position\_initial}{nb\_points * total\_time} \tag{1}$$

$$total\_time = nb\_points*(integration\_time+latency\_time) \tag{2}$$

Fixed formulas:

$$velocity = \frac{position\_final - position\_initial}{(nb\_points - 1) * total\_time} \tag{3}$$

$$\begin{aligned} total\_time = {} & (nb\_points * integration\_time) + \\ & (nb\_points - 1) * latency\_time \end{aligned} \tag{4}$$

The issue was resolved by using a meshct scan with overwritten formulas.

The Overhead per Line

Normally, in a meshct scan, Sardana arms the detectors for every step of the slower motor. This adds a lot of extra work for each line. To fix this problem, additional changes to the

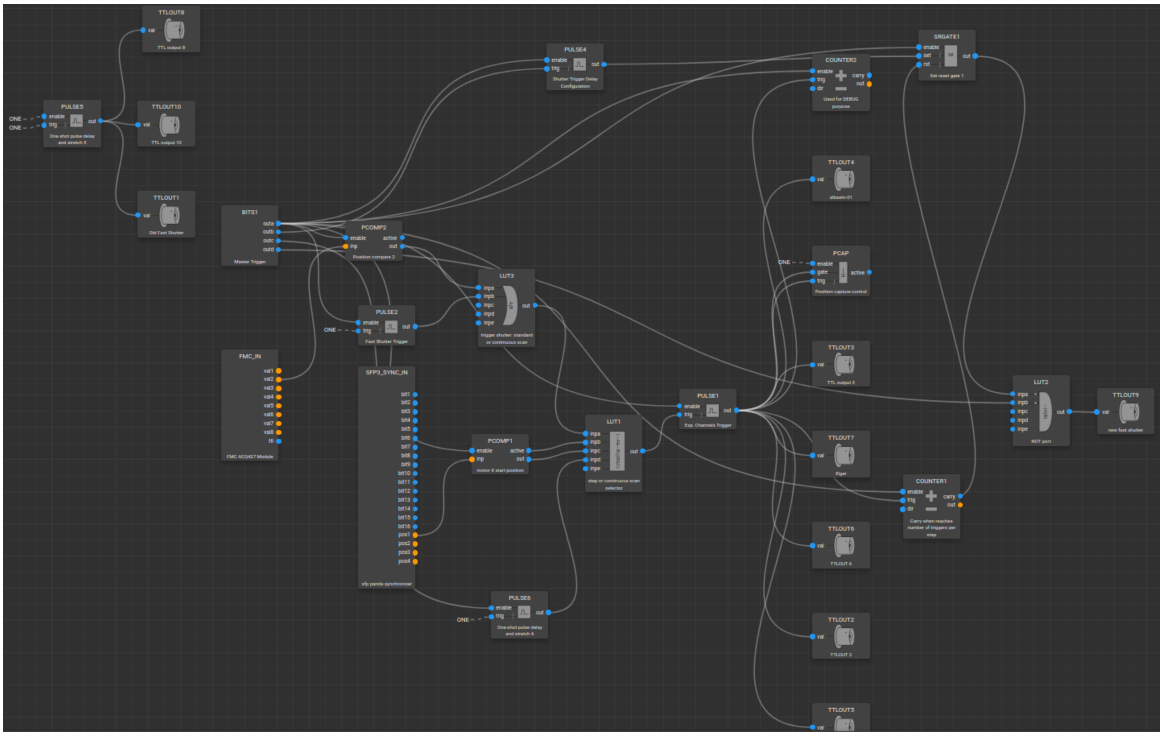

Figure 3: The PandABox schema.

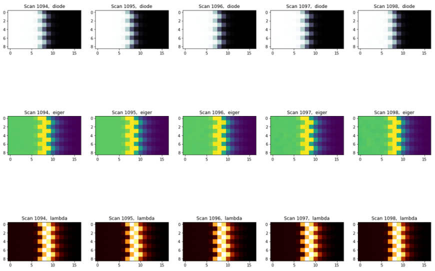

Figure 4: The drift issue.

meshct class were made so that the detectors are armed only once for the entire scan, reducing unnecessary overhead. For the meshct scan in snake mode with measurement group consisting of Eiger, Lambda, AlbaEM and PandABox's PCAP the overhead per line improved from 3.04 s to 0.732 s.

CONCLUSION

The amalgamation of TANGO Controls, Sardana, PandABox, and IcePAPs ensures the comprehensive and robust nature of the control system, ultimately optimizing the ForMAX beamline's performance for a diverse range of experiments. After making the mentioned improvements, scans have become considerably quicker. The next task involves enhancing the way the two motors work together in meshct scanning to reduce the time spent at the end of each scan line. In a meshct scan, the slower (step) motor begins moving only after the faster (continuous) motor reaches the end position. This setup slows down the scan between two lines more than anticipated.

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REFERENCES

[1] MAX IV Laboratory home page, `https://www.maxiv.lu.se/`

[2] TANGO Controls, `https://www.tango-controls.org/`

[3] Sardana, `https://sardana-controls.org/index.html`

[4] PandABox, `https://www.ohwr.org/project/pandabox/wikis/home`

[5] H. Enquist *et al.*, "Continuous Scans with Position Based Hardware Triggers", in *Proc. ICALEPCS'21*, Shanghai, China, Oct. 2021, pp. 1069–1073. `doi:10.18429/JACoW-ICALEPCS2021-FRBR04`