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# PRELIMINARY SCANNING INTEGRATION AT MAX IV BEAMLINES

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*Abstract*

The MAX IV Laboratory is in a stage where beamlines are starting to welcome users that will collect data utilizing various scanning methods. This paper focuses on the different motion and synchronization techniques, hardware integration, software solutions, data acquisition and experiment supervision at MAX IV beamlines.

## INTRODUCTION

The objective of a scan is to vary certain physical parameters of a machinery while acquiring sample images/data together with other relevant attributes for metadata purposes and eventual result adjustments/corrections. Step and continuous scans plus their variations (hybrid scans) are the most common.

Step scans are mostly position based. A scan macro defines a group of motors with their position set points, group of acquisition devices, step period and amount of steps. Once the scan is launched, motors follow the defined trajectory and the group of detectors/acquisition devices collect data for each set point. Step scans are generally software based, e.g. a program manages each step's transitions and acquisitions.

Continuous scans are a bit more complex. The data acquisition is carried out as, at least, one of the motors is moving continuously along a predefined stroke. That implies the need of hardware to associate the data points to the position of the motors where that data was collected.

If the scheme is time based, that hardware will take not only the role of triggering the acquisition devices in the scan, but also to sample the positions of the motors at each point.

If, on the other hand, a position based scheme is used, that hardware will have to monitor the position of the moving motor and generate triggers as target positions along the stroke are reached.

The selection of the scheme to be used, either time or position, will be done by the availability of suitable electronics, scan timing performance, error budgets and the nature of the experiment itself.

## HARDWARE

A variety of hardware elements are present in the data acquisition setups in synchrotron beamlines. Motion controllers steering actuators like steppers or piezoceramic stacks in closed loop against encoders based on optic, magnetic, interferometric and other effects run across a predefined trajectory, while different detectors like CCDs, electrometers, ADCs, counter cards and other electronics acquire data gated by some hardware unit that at the same time can distribute other digital signals to open shutters and valves.

### *Motion Controllers*

Beyond 75% of the axes in MAX IV Laboratory are stepper motors. IcePAP [1] has been chosen as our standard motion controller. This motion controller offers multi-axes synchronization for a wide range of steppers allowing at the same time for seamless control of external drivers of other motor technologies (e.g. Digitax ST servo drivers etc.) in a single electronic card, simplifying installation and maintenance. The driver can output its position reference or any encoder input to synchronize with other motion controllers or to capture position data. Furthermore, a set of digital I/O enables to both, output internal states in the driver to external hardware and to trigger internally generated movements.

The scenario for piezoelectric actuators is a bit more fractioned as there are different techniques under this term. The different piezo electric linear stacks, slip-stick motors, walkers and the incompatibilities between drivers, that vendors offer for them, create a slowly growing set of different controllers that often are not thought with integration in a complex data acquisition setup like a synchrotron beamline in mind and that furthermore increase required support from the different teams involved.

To mention a few, Physik Instrumente (E-625, E-725 series), Smaract MCS, Attocube ECC are already present in some of the MAX IV Laboratory setups. The diversity in communication buses, I/O-s, internal resources, features implementation, calibration requirements and heterogeneous offer of available actuators forces to study carefully the current requirements and their possible future evolution before purchasing.

### *Encoders*

Encoders are not only used in setups to close the different actuators position loops but also as a source of data that is captured together with that of the rest of detectors. That set specific requirements on the motion controllers or on external electronics used to capture that data.

A number of different technologies are used in synchrotron beamlines to measure position, optical and magnetic encoders, strain gauges and interferometers. For scanning purposes, the nature of the transducer itself is as important as the signal scheme used to bring the data into the control system. Incremental and absolute (SSI, BISS-C, EnDat) encoders are the most common and are compatible with most motion controllers but other schemes based on simple analog voltages or currents can appear and require additional solutions.

### *Other Hardware*

Industrial PC cards like counters and ADCs are used for a number of purposes within the measurement setups as the examples below describe. Among others, acquiring analog

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signals from position sensors, counting pulses from photon sensing detectors or from voltage-to-frequency converters attached to current amplifiers or generating gates and other triggering signals during the measurements are the most typical. These cards have normally many features and have proved to be more than enough for the current applications. Despite that, they lack full access to the internal resources that other systems based on FPGAs can offer and that may be necessary in future and more complex applications.

## STEP SCANS

A classical example of step scans are energy scans. The aim is to move the optics in the monochromator to a new position in a way that light with another energy is available through the exit slit and then stand still until the measurement is done. Many times the insertion device and the rest of the mirrors in the beamline stays in their positions during the entire step scan but if they move, the measurement will not start until all objects reach their final destination.

The angles of a monochromator need to position its optics in order to reach a certain energy can be calculated by first starting with the basic grating equation for diffraction and then introduce a fixed focus condition, $c_{ff}$, defined by $c_{ff}^2 = \cos^2(\beta)/\cos^2(\alpha)$, originally described by [2] and others. The angles on the mirror and the grating are, for a given energy then set by the quadratic equation

$$(1 - c_{ff}^2)\sin^2(\beta) + 2c_{ff}^2\frac{m\lambda}{d}\sin(\beta) + c_{ff}^2 - 1 - \frac{m^2\lambda^2}{d^2}c_{ff}^2 = 0 \quad (1)$$

where $m$ is the diffraction order, $d$ is the ruling spacing of the grating, $\lambda$ is the wavelength of the light, and $\alpha$ is the normal incident light on mirror.

The users at MAX IV have several options to make a scan as we are using Tango [3] and Sardana [4] as our control system components. A simple scan is set in Taurus [5] by start, stop, step, time variables through GUIs accessed through synoptics [6]. Then, the selected item to be scanned, often a pseudomotor incorporating (1) will move the mirror and grating from energy to energy as requested, pause motion and trigger devices to allow measurements and then continue until the end.

The sampling time varies from fractions of seconds to hours depending on the experiment and during this time the optics should be as free of vibrations as possible. Short term vibration is best avoided already in the design phase of the individual systems by pushing the self resonance frequency to high values. At MAX IV, a design request is to stay above 50 Hz. Other sources of noise are turbulence in cooling water in optics, which should be reduced to a minimum as seen in Fig. 1 where noise is measured on Veritas monochromator mirror first with maximum water flow and then completely turned off. The noise is reduced by a factor of five between those extremes. Vibrations from pumps are yet another important source, which makes ion pump an attractive solution.

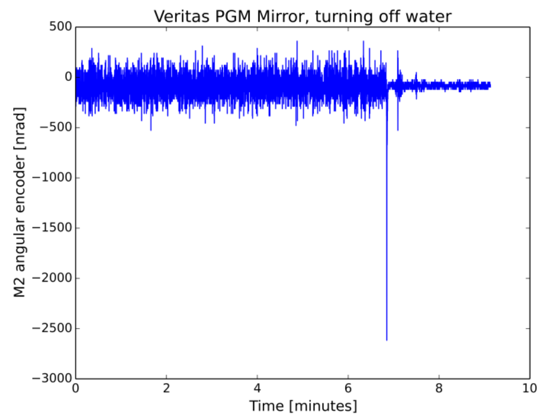


Figure 1: Noise in the monochromator mirror is reduced by a factor of five when the two valves controlling the flow are closed.

Measurement examples on Veritas beamline for a step scan on the monochromator mirror is shown in Fig. 2, where the ten individual steps up and down are reduced to barely be separated from the noise in the system as a test of the resolving power. In this test, the closed loop is turned off as can be seen as the steps are not exactly equally long due to drift. Each step is ten seconds long and the water flow is turned off. The target resolution on Veritas is 100.000 E/dE which means that at 1000 eV the mirror should be able to take less than 220 nanoradians per step, while for the grating it is enough with less than 300 nanoradians per step for the 1221 lines/mm grating, which is reached as the steps are roughly 50 nanoradians high. As seen in Fig. 1, this margin is easily erased by e.g. uncontrolled cooling water flow.

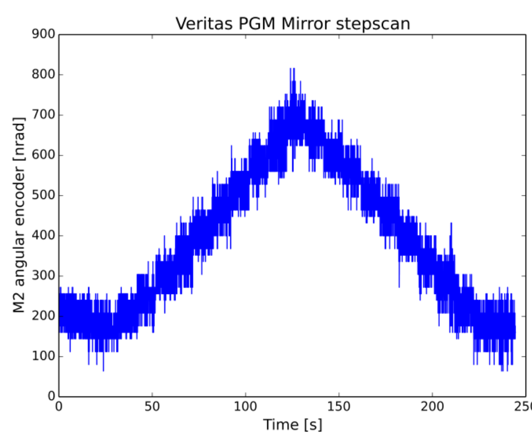


Figure 2: Veriats monochromator mirror during a step scan of 10 up and down steps, with 10 seconds of sampling time in open loop.

For the longer measurements, the ability to stay in the same position over time is crucial. In Fig. 3 the angle of Veritas monochromator mirror is recorded over two weeks operating in closed loop. The closed loop prevents the mirror of drifting away from its position.

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The drift could be caused by vacuum forces, relaxing tension in gearboxes and other sources of forces. Another source is temperature drift that causes mechanical drift, which puts demand on temperature controlled environment. In MAX IV, optical hutches are temperature controlled to 0.1 degrees.

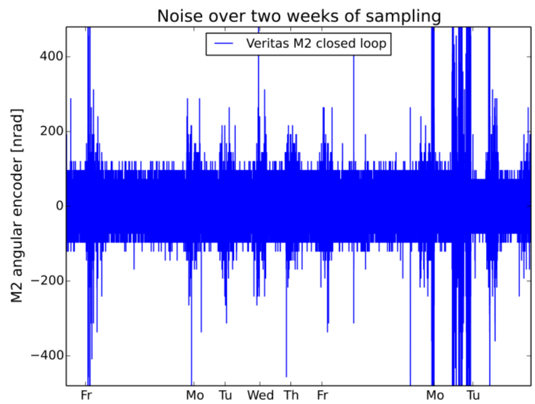


Figure 3: Monochromator optics controlled by stepper motors operating in closed loop have the ability to hold a steady position for long measurements.

One can also note in Fig. 3 that the best performance of the system is during weekends and night, as the ongoing construction on the facility (MAX IV was, at the time of the measurement, still a construction site) introduce additional noise from 7.30 every morning.

## CONTINUOUS SCANS

Initially, MAX IV has utilized two types: position and time based with maximal acquisition (discretization) frequency below 1 kHz.

In case of position based scan (see Fig. 4), a main motion controller acts as a scan master and has to be programmed with a certain trajectory movement of its axises. A predefined table *trigger=f(position)* defines a synchronization trigger occurrence for the scan acquisition group (DAQ devices, detectors etc.). The main advantage is that this solution does not require any extra timing electronics in general.

In case of time based scan (Fig. 5), a main motion controller acts as a "semi-master", it contains predefined trajectory *position=f(time)* (generally $V$[m/s] = $const$) and generates the $start - stop$ gate signal (based on the $min/max$ position threshold) which is fed to a beamline timing. Once the gate is received, the timing takes the role of the master and discretizes the gate pulse into a frequency, feeding acquisition devices and motion position recorders as well.

An initial evaluation has been done at Nanomax beamline and the time based solution has been selected as acquired images (detector data) had a better performance in terms of accuracy and noise. The reason is related to noises of axis encoders as mechanics has higher jitters than electronic oscillators, synchronous and asynchronous processing electronics (below nano seconds).

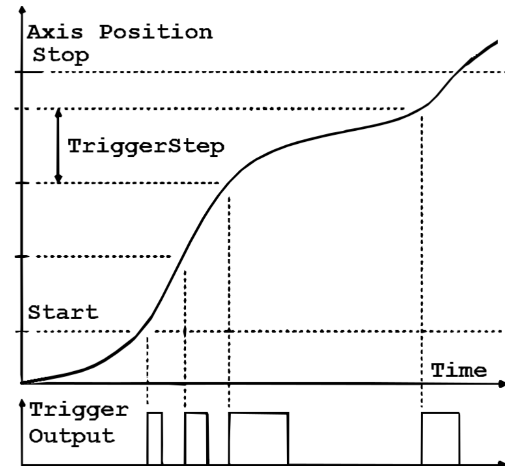


Figure 4: Position based scan.

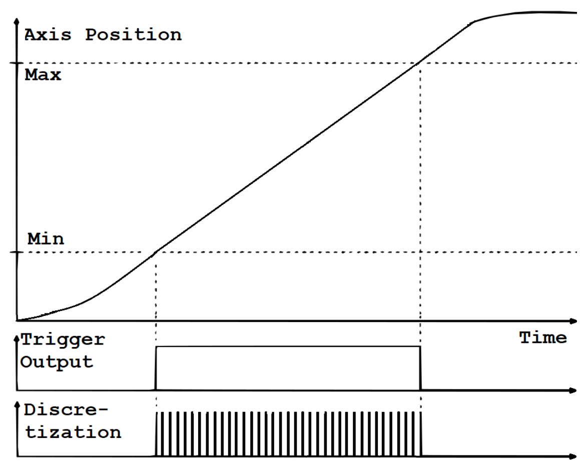


Figure 5: Min/max time based scan.

### *Nanomax Beamline*

At Nanomax [7], the scanning process is based on two piezo motors ($x$ and $y$, controlled by PI E-727 with 100 µm range), where one moves continuously ($x$) for a range of steps in the other ($y$). The scan may typically be 100x100 points. At each point a detector (Dectris Pilatus 100K or 1M) is triggered, with an exposure time which can be as short as few ms, thus giving 0.5 s for one "line" (one scan of 100 points in $x$) and 1 minute for a single complete 2d scan (100 points in $x$ for 100 lines in $y$). The actual achieved image accuracy is around 50 nm but targeted is around 10 nm.

The Fig. 6 presents a graphical process of the Nanomax scan where the piezo controller acts as a scan master.

The principle is as follows:

- The user requests a 2d scan, which is hardware-continuous in $x$ and software-stepped in $y$ (Sardana [4] ascan [8] in $y$). This implementation involves step and continuous scan methods together, making a hybrid scheme.
- Input scan parameters are start position, end position, number of intervals in $y$ (in the usual way), number of intervals in $x$ and the integration time.

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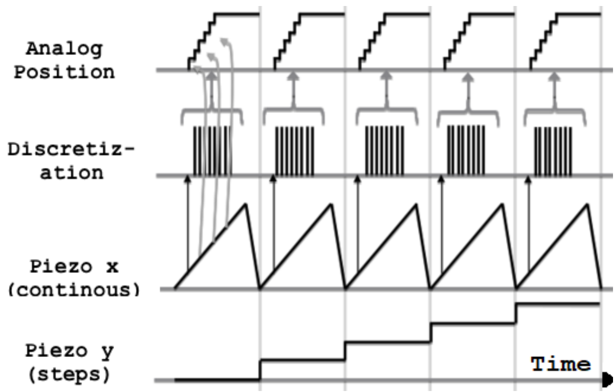

Figure 6: Time-based scan structure at Nanomax.

- The *y* dimension works like a usual step scan. For the *x* dimension, the piezo controller will repeatedly follow a preprogrammed waveform (a ramp).
- The piezo controller generates a trigger output gate during the *x* motion (see Fig. 5). This gate is sent to a data acquisition card (DAQ-2005 by Adlink) and during this time the card sends trigger pulses. The frequency is such that the *n* pulses fit into the time window of the linear motion.
- The trigger pulses are sent to the detector, other acquisition group (diode detectors with a gated/integrated acquisition etc.) and to the acquisition card. Here the card reads the analogue voltage output from the piezo controller, giving the positions of the piezo (*x*). The acquired data is buffered, thus the readout is time synchronized.
- At the end of one line, before moving the step in *y*, Sardana reads the buffered data from the card and detector records.

The min/max threshold (see Fig. 5) implementation removes the undefined acceleration time related to a motor type and its mechanics. Basically, a motor has time to reach to its working velocity before *min* position threshold and slow down after the *max*. In close future, a beam shutter will be synchronized with the trigger output gate as well, so the X-ray will be applied to the sample/experiment only during the *x* movement.

## CONCLUSIONS

Nowadays, software solutions are very versatile and therefore may be adapted daily to meet new user requirements in a beamline environment. If a required scan performance is not outside the software capabilities, the preference is to skip adding extra hardware, decreasing maintenance and flexibility difficulties.

MAX IV utilizes standard acquisition electronics: NI-6602 (by National Instruments), DAQ-2005 and DAQ-9114 (by Adlink) which support open source (GPLv3 license [9]) libraries (APIs) and Tango [3] devices.

The choice of IcePAP [1] as standard motion controller has also proven to be a success, since it covers 75% of MAX IV needs and can interface to some drivers for actuators not directly supported like piezos or servos.

The acquisition devices make another big group: Dectris Pilatus detectors, ionization chambers, X-ray position monitors (XBPMs) and electrometers. EM# by Alba [10] synchrotron: [11, 12] has been selected as a general purpose electrometer at MAX IV.

If the existing hardware becomes not sufficient for new scan requirements, a future intention is to evaluate other synchronization devices like MUSST [13], Zebra [14], PandA [15], PiLC [16].

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