THE SIRIUS MOTION CONTROL REPORT

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Abstract

Sirius is the new 4th generation synchrotron light source being built in Campinas, Brazil. The motion control report was created to describe all the steps taken to choose the set of motors, motor drives, and controllers that the hardware (GAE) and software (SOL) support groups will recommend. The steps include researching motion control systems in other Synchrotron laboratories, talking to the Sirius beamline designers, defining requirements and testing. This presentation describes the report, showing the information gathering process and latest results.

INTRODUCTION

The method to define the motion control solution for Sirius will be based in 7 steps:

1. Description of current motion control systems from the UVX synchrotron at LNLS, Brazil, and also from other laboratories, so that it is possible to have a base reference of what can be done and what are the current established practices related to motion control.
2. Definition of the requirements for the Sirius motion control system. It focuses on deciding, together with the beamline operators and scientists, what will be necessary for the motion control system to provide (precise movements, coordinated movements, fast movements, etc). It will also include requirements suggested by the support groups, either because they are useful (debugging support, installation on standard racks, etc), or necessary (adherence to safety standards, availability of software drivers, etc). Also, it will be considered the current expertise in equipment used in UVX as a requirement.
3. Initial device selection, where the requirements are formalized and the list of possible devices is presented. The result of this step is a filtered and standardized description of everything that beamline operators need from the motion control system and also a list of devices that will be part of the selection process.
4. Definition of tests. A set of tests will be elaborated in a way to identify the devices that comply with the requirements or not. The result of this step is a set of programs, types of equipment and textual descriptions necessary to execute the tests.
5. Execution of tests. All devices that we can acquire from the pre-selected list will be tested as necessary. The result of this step is a list of devices that passed the tests.
6. Reevaluation of tests. This step is basically doing the fourth and fifth steps again, if necessary.
7. Final device selection. The devices will be selected according to tie break rules. The result of this step is the set of recommended motion control devices for Sirius, which complete the report.

CURRENT STATE OF MOTION CONTROL SYSTEMS

The UVX light source at LNLS uses motors in the beamlines to control the beam setup, for example, to place mirrors in position, and also to control the experiments, for example, by selecting the energy from the monochromator.

Controllers

The main controllers used are the Galil DMC-4183 and Parker OEM 750X, which also has an integrated driver. There are a few IMS (integrated controller and motor) models 14A4, 17C4-EQ and 23C7-EQ and a few All-motion, models: EZHR17EN and EZHR23NHC.

Drivers

Basically, there are 3 drivers in use: Galil DMC 4140, Parker OEM750X, and Phytron ZMX+.

Motors and Control System Setup

There are many examples of motors used for beamline setup. For example, there are motors for positioning the first mirrors on the beamline entry point. The mirrors position the beam before entering the monochromator. The monochromator base may also contain motors, which will influence both the entry and exit positions of the beam at the monochromator. After the monochromator, motorized slits will select relevant parts of the beam, for example, the most uniform section of the beam, or some part with certain polarization properties. Another motorized set of slits farther away from the monochromator blocks scattered light. The table that holds all the equipment after the monochromator may rotate starting from the monochromator, to guide the light exiting the monochromator at different angles.

All those motors are used to set up the beamline, for example, to focus the beam at a precise point or to select the energy on fixed energy beamlines. They are set up before the experiments start.

Other motors are used during the experiment. Motors may move inside the monochromator to select the energy while doing scans. Sample holders move to select and position different samples to be tested. The samples or the cameras may be rotated to measure diffraction at different angles. The undulator needs to move synchronized with the monochromator to select different energies.

The motor types used at UVX are stepper motors and piezo. The stepper motor brands are Arsape, Haydon Kerk,

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IMS, Kalatec, Lin, Newport, Parker, Phytron, Sanyo Denki, Slo Syn, Syncro, Thorlabs, and Vexta. The piezo motor brands are Newfocus, Newport, and Pi. Some Phytron motors are specially built to operate in the vacuum.

Motion Control Software

The LNLS control system is almost completely standardized on using the EPICS [1] middleware. EPICS exports remote resources representing devices as remote variables (called "process variables") and organized into records. Motors are exported as motor records [2], with each kind of controller having its own server (called "IOC", or Input/Output Controller). Movement commands or automation is achieved by using scripts sending commands to change and read process variables. For example, a scan script, typically written in python, will connect to the process variables representing slits, change the process variable to move the slit motors to the new position and then measuring beam intensity by reading a process variable representing a photo-diode. This allows doing beam alignment.

Beamline operators may either write their own scripts from zero, or they may use the Py4Syn [3–5] library, developed at LNLS, which contain common procedures, like doing scans, plotting, fitting and storing data files. A set of example front-end scripts, that uses Py4Syn, is also available for beamline operators that don't want to program anything.

MOTION CONTROL IN OTHER ORGANIZATIONS

Research articles [6–43] explaining or citing parts of the motion control choices in other synchrotron labs were collected. Other particle accelerators with participation in ICALEPCS 2015 were also researched [44–51]. Also, e-mails were sent to some labs to gather direct information.

VME Devices

The following organizations use or have used VME controllers:

- CLS, BESSY, LCLS, PETRA, SSRF and SLS: OMS MAXv controller.
- DELTA and SLS: OMS VME58 controller.
- RHIC: OMS VX2 controller.
- APS and BESSY: Delta Tau PMAC2-VME controller.
- Spring-8: Advanet Advme2005 controller.

The combination of the VME motion controller with other VME devices and VxWorks is used to provide an integrated deterministic control system.

In-house Developed Devices

Some organizations have opted to develop devices or parts of devices in-house, the most evident example being the IcePAP system, developed by ALBA and ESRF and expected to be adopted by MAX IV and Solaris. IcePAP is composed of a rack with power supply, the controller, and driver boards. Up to 16 racks can be linked together to control a total of 128 motors. The IcePAP development was motivated by reducing compromises perceived to be present with off-the-shelf controllers. The project goal was to optimize functionality, performance, ease of deployment, a level of standardization and cost.

Another custom device is the YAMS system, developed at Elettra. The system uses a Galil DMC-21x3 controller as the basis of the project. It includes a rack for controller and drivers. The driver boards are custom designed, using the IMS/Schneider Electric IM48xH/IM805H micro stepping drivers. Encoder daughter boards were also designed. The YAMS development was motivated by standardization and costs.

Other in-house custom devices are an RS-485 based motion control system developed at RRCAT using the Texas Instruments LMD18245 driver chip and at Spring-8, a DeviceNet PLC based controller, and the PC-based Blanc4 controller.

Host Communication Protocols

There are many protocols and buses available for communication with the host machines or the rest of the control system. Some of them are listed here:

- Newport ESP7000: GPIB, RS-232 and USB
- Delta Tau PMAC2-VME: VME
- OMS MAXnet: Ethernet+TCP/IP and RS-232
- Galil DMC-21x3: Ethernet+TCP/IP, Ethernet+UDP/IP and RS-232
- OMS MAXv: VME
- Newport XPS: Ethernet+TCP/IP
- Parker 6K: Ethernet+TCP/IP and Ethernet+UDP/IP
- Delta Tau Turbo PMAC2: VME
- Delta Tau GeoBrick LV IMS: Ethernet+TCP/IP, USB and RS-232
- Adlink PCI-8134: PCI
- OMS VME58: VME
- Hytec IP8601: VME+IndustryPack
- IcePAP: Ethernet
- National Instruments PCI-STEP-4CX: PCI
- Attocube ANC300: Ethernet+TCP/IP, USB and RS-232
- Aerotech Ensemble CP10: Ethernet, USB and RS-232
- OMS VX2: VME
- Newport MM4006: RS-232, GPIB and RS-485
- Galil DMC-4183: Ethernet+TCP/IP, Ethernet+UDP/IP, USB and RS-232
- Delta Tau Power PMAC: Ethernet
- Tsujicon PM16C: Ethernet+TCP/IP, RS-232 and GPIB
- Advanet Advme2005: VME
- Interface Corporation PCI-7414M: PCI
- Galil DMC-1000: ISA
- Delta Tau PMAC PCI: PCI
- Galil DMC-40x0: Ethernet and RS-232

High Precision Devices

While there have been well-described efforts to standardize stepper and servo motor controllers in other labs, no

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related efforts seem to have been done for piezo motors. For example, in MOCRAF 2015, it has been described the NSLS-II usage of a Delta Tau and Newport controllers for stepper and servo motors, while the list for piezo motors is composed of SmarAct, Attocube, PI, PiezoJena, and nPoint.

High precision may be used when building instruments, like microscopes or interferometers and on beamlines they are typically used to move sample holders or focusing and correcting small-scale positioning errors. A more specific use case exists at BESSY, a Nanomotion HR8 piezo motor is used to rotate the monochromator grating and mirror. Outside beamlines, the European XFEL has described at ICALEPCS 2015 the piezo-based cavity fine tuner, which reduces deformation on the accelerator's walls.

Complex and Coordinated Motion

Motions that happen on an arbitrary nonlinear path over time will be considered complex motions in this paper. Coordinated motion is a motion that simultaneously moves more than one motor.

Examples in complex motions: to change the monochromator energy in fixed energy steps, nonlinear movement with variable speed is required by the monochromator motors between each step. If a slit can move independently its top, bottom, right and left blades, then the operation of increasing the gap in the slit is a linear coordinated movement.

A nonlinear movement may also happen at a lower level, like in piezo devices, which may be nonlinear in nature. With the help of position encoders and closed loop feedback they might be translated and interpreted at higher levels as linear movements, if necessary.

An example of complex motion at SOLEIL comes from the ICALEPCS 2015 report on the REVOLUTION project. A beamline had its motion controller switched to a Delta Tau Power Brick to control the beamline energy selection. Seven equations were implemented to translate the required energy to the positions of each of the seven motors inside the monochromator so that only the high-level request for a specific energy is required. The goals of the implementation were to reduce communication with the host machine and to allow continuous energy scan operations.

At BESSY, a Nanomotion HR8 piezo motor uses a Delta Tau PMAC2-VME controller with a custom nonlinear model and closed loop feedback to overcome the encoder precision limitations when moving the piezo motor in very small steps. The motion also needs to be synchronized with the undulator for correct energy selection.

Another example of complex and coordinated motion is the SLAC LCLS fast wire scanner, used for beamline emittance diagnostics, which uses the S-curve available in the OMS/ProDex MAXv controller.

REQUIREMENTS FOR THE SIRIUS MOTION CONTROL SYSTEM

UVX as the Baseline

The beamline requirements for Sirius might not be well defined. For example, the beamline operators and scientists may not know what they need. The current motion control environment in UVX may be used as a baseline for these cases. Knowledge and expertise on the current solution are also considered requirements with strong importance. This is because it took years of work from LNLS workers to understand, correct and develop hardware and software until the system stabilized. Probably this work needs to be redone when choosing different components.

Standardization of Components

We expect to follow an 80% / 20% rule, considering a cheap and simple solution for 80% of the motors and an expensive, precise and resource-full solution for the remaining 20%, regarding complex and coordinated motion. In particular, we expect that a single selection of components will be useful for the majority of use cases. For the more specific cases either one or more sets of components will be required, the less, the better for administration and maintenance costs.

Requirements for the New Beamlines

Currently, out of the 13 initial beamlines planned for Sirius, 5 of them have an approved preliminary design report. We have talked to the beamline scientists about the motion control system of these 5 lines and also with 1 other scientist for the remaining beamlines. The discussed requirements are detailed below.

Sapucaia The Sapucaia beamline will be an SAXS beamline, with support for doing "nanobeam" experiments.

The main beamline elements are:

- the initial slits after the protection wall
- a double crystal monochromator
- a positioning mirror
- two sets of slits for slicing and focusing the beam
- kinoform lenses to focus the nanobeam
- the sample holder stage
- the X-ray detectors, that detect light scattered from the samples.

Cateretê The Cateretê beamline is defined as a coherent and time-resolved X-ray scattering beamline. It will support time-resolved small angle X-ray scattering (SAXS) and ultra-small-angle X-ray scattering (USAXS), which are techniques for structural studies of nanoparticles, coherent diffractive imaging (CDI), a technique for 3D imaging with 30 nm resolution that uses coherent X-ray scattering instead of lenses and X-ray photon correlation spectroscopy (XPCS), for studying dynamics of nanoparticles using fluctuating patterns generated by coherent X-ray scattering.

The main beamline elements are:

- the undulator at the storage ring

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- the initial slits
- a double crystal monochromator
- a focusing mirror
- a set of slits for slicing the beam
- the sample stage
- the detector stage

Carnaúba The Carnaúba beamline is defined as a nano focus beamline, providing a beam focused to a diameter of up to 80 nm. It targets fluorescent and absorption techniques, as well as imaging based on X-ray scattering.

The main beamline elements are:

- the undulator at the storage ring
- the initial slits
- a focusing mirror
- a second mirror for positioning and removing harmonics
- a set of slits used as the secondary light source
- a 4-bounce crystal monochromator
- a set of slits after the monochromator to slice the beam
- a Kirkpatrick-Baez mirror for focusing the beam at nanometric scale
- the sample holder station

Ipê The Ipê beamline targets soft X-ray spectroscopy, with an energy range of 100 eV to 2.000 eV and will have two separate experimental end stations for two different techniques: resonant inelastic X-ray scattering (RIXS), which uses emitted photons, and near ambient pressure X-ray photoelectron spectroscopy (NAP-XPS), which uses emitted electrons to perform the spectroscopic measurement. The main beamline elements are:

- the undulator at the storage ring
- a first mirror used as a filter to reduce thermal load
- a grating and mirror (planar grating) monochromator
- a deflecting mirror used to switch between the two end stations
- a set of slits after the monochromator to slice the beam before each end station
- focusing mirrors for each end station
- sample stages on each end station
- detector stages on each end station

RESULTS AND DISCUSSION

Step 2 of the motor selection procedure was concluded and the requirements were partially described in this paper. Next step, the initial device selection will start.

CONCLUSION

An extensive work needs to be done to finish this procedure. When we have the final results a new report will be written.

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