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CONTROL SYSTEM INTEGRATION OF MAX IV INSERTION DEVICES

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Abstract

During the last 3 years, MAX IV has installed and commissioned in total 15 insertion devices out of which 6 are new in vacuum undulators, 1 in vacuum wiggler, and 7 in-house developed and manufactured Apple II elliptically polarized undulators. From the old lab, MAXLAB, 1 PU is also reused. Looking forward, 3 additional insertion devices will be installed shortly. As MAX IV only has one Control and IT group, the same concept of machine and beamline installation have been applied also to the insertion devices, i.e. Sardana, Tango, PLC, and IcePAP integration. This has made a seamless integration possible to the rest of the facility in terms of user interfaces, alarm handling, archiving of status, and also future maintenance support.

INTRODUCTION

The purpose of a synchrotron facility is to create a flux of photons that can interact with atom electron shells of a variety of samples that range from proteins crystals to semiconductors. The photon flux is created by forcing a highly relativistic beam of electrons to deflect back and forth over its ideal golden orbit by making them travel along a row of permanent dipole magnets with alternating polarity.

The devices hosting the magnet arrays and the mechanics to move them around the beam are called insertion devices (IDs). If the magnet arrays are arranged to give a broad photon energy spectrum, the system is called wiggler. A different arrangement named undulator gives a more narrow photon beam spectrum, and within that group a subset called elliptically polarized undulators allow to adjust the phase characteristics of the output beam. The energy of the photon spectrum is controlled by changing the distance between the permanent dipole magnets and the electron beam while changing the relative position of the magnet arrays modifies the polarity of the photon beam.

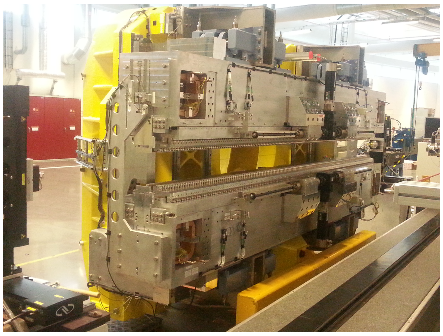

Figure 1: Softimax EPU under test and assembly in MAX IV magnet lab.

Figure 2: Each EPU girder has two subgirders that host the magnet arrays and can move relative to each other and to the subgirders in the other girder. Together they determine the polarization of the light.

All the insertion devices share the same mechanical principle of two girders, an upper one and a lower one, Fig. 1. The distance between these girders defines the gap mentioned above. Besides that EPUs girders are divided in two subgirders that can be shifted longitudinally with respect to each other, Fig. 2. The mechanically simplest insertion devices are the IVUs at Cosaxs, Danmax and Femtomax beamlines which have a single motor that acts on the distance between girders; more complex setups like the Wiggler in Balder beamline have two motors that act on the gap at both girder ends, allowing to increase the gap at both ends independently, giving the option to tilt the girders; one last type of IVUs, present in Biomax and Nanomax beamlines, have four independent motors at each girder end, adding the posibility of introducing a different offset between each girder and the photon beam plane. Ultimately, the EPUs are equipped with 4 extra motors (8 in total) that allow to move independently their 4 subgirders in the horizontal plane. The girders can be up to 4 m long and weight up to 13.5 tons. The massive structures in Fig. 1 are needed as the maximum attractive force between the top and bottom girder is 46 kN while the maximum repellent force is 30 kN dependent on subgirder phases.

The maximum longitudinal force is 35 kN and the maximum transversal force is 7 kN. As the force between permanent magnets is not linear with distance, closing the gap will cause an ever increasing rate of attractive force as the gap is closed. This causes the entire casted iron structure to bend dependent on gap and phase. From a mechanical point of view, the magnets on the girders can be moved to 0.5 mm far from the beam vacuum chamber, but as this would create too high heat load is not allowed in operation.

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Positioning the IDs requires sub μm control over these heavy mechanics that as stated above, depending on the phase of the magnets, are either pushing or pulling with several tens of kilo newtons.

Typical safety requirements of an ID are to avoid crushing the vacuum tubes where the electrons travel or closing the magnet arrays in a way that the beam can melt the mechanical structure or hit metal creating bremsstrahlung radiation. Besides that the ID should be operated both from the accelerator control room as well as from the beamline, preferably in synch with the beamline monochromator, with the accelerator control room having priority and the possibility to lock the operation. The ID should also be safe to maintain inside the storage ring without the possibility that someone remotely starts the motors.

At the moment, the MAX IV rings host a mixture of 6 new in-vacuum undulators, 7 in-house developed and manufactured Apple II elliptically polarized undulators [1], 1 in vacuum wiggler together with 1 reused PU from the old lab, MAXLAB. In total, 15 IDs have been installed and tested while 3 IDs are planed for the near future. The facility has now reached a state where 11 beamlines with their respective IDs are in simultaneous stable operation and receiving light from the 1.5 GeV and 3 GeV rings.

CONTROL SYSTEM

Low Level Hardware

The six IVUs and the Wiggler are equipped with different flavours of stepper motors chosen by the equipment manufacturer. At procurement time, the interface boundary was set at the driver level, that was part of the deliverables as well.

The EPUs require the movement of heavier structures at speeds where brushless DC servomotors are the best option.

All motions have been equipped with absolute encoders to simplify operation, avoiding possibly complicated homing procedures. Wherever the equipment protection system required position information, separate encoders, also absolute, where installed.

All devices allowing taper in their motion schemes are equipped with sensitive tiltmeters to prevent forcing the mechanics unnecessarily.

Precision switches have been used to limit the motion stroke of all axes, that, moreover have a second pair of overtravel switches to directly kill the driver power stages in the unlikely situation of a limit-switch failure.

Thermocouples and vacuum sensors are available to monitor the state of the devices with components under vacuum.

In order to rectify the alterations to the beam orbit caused by the magnetic structures of the IDs, corrector coils are fitted at the entrance and the exit of all the devices.

Motion Controller Layer

IcePAP [2] is the MAX IV Laboratory standard motion controller in all applications, which simplifies synchronization with other motorized elements and reduces the effort at the software level and the learning curve for operators, users and engineers. With that in mind, equipment manufacturers were requested to provide machines with motors and drivers of their choice with the requirement of having a quadrature or pulse/direction interface as position reference suitable to be rack mounted, Fig. 3. For axes with external drivers, IcePAP manages motion profiles and closed-loop positioning and the upper layers rely on the IcePAP system functionality for inter-axes synchronization. A basic handshake between controller and external drivers allows to power on the external driver and know when it is ready to accept motion commands.

Figure 3: EPU control cabinets.

Limit switches, encoders and a disable signal for equipment protection from the PLC unit are directly routed to IcePAP as well.

Equipment and Personal Protection Systems

A Rockwell Allen-Bradley PLC takes on all equipment protection responsibilities. This equipment receives the signals from the different sensors mentioned above: overtravel switches, tilt sensors, thermocouples, encoders, contact switches for protection panels, water sensors and generates a signal that disables IcePAP and the external drivers power stages in case the whole system exceeds the allowed operational parameters.

Wherever the equipment and its surroundings create hazards that require safety rated de-energizing of the power stages, the PLC was equipped with modules that offer the adequate certification to interface the safety rated inputs available in the selected external drivers.

A key-based system is available in all motion cabinets to override the disable functionality and allows expert personnel to take correction measures and bring the equipment back to normal operation.

Corrector Power Supplies

The interaction of the electrons in the storage ring and the magnets of the insertion devices distorts the path followed by the beam. The magnitude and direction of the distortion is dependent on the gap and phase settings of the insertion device. Coils at the entrance and exit of the device allow to correct these deviations. Fast bipolar power supplies have been used for that purpose.

Motion Control

At MAX IV Laboratory, machine and beamline networks are split. The virtual machines where the motion control software for all MAX IV insertion devices are located in the machine network.

Each insertion device is controlled through Sardana [3] (one Sardana instance per ID). All motors are exposed in the Sardana pool and can be moved individually. Pseudomotors (on top of those motors) convert motor positions to insertion device properties (gap, taper, offset, phase, ...) and manage motion synchronisation.

ID motion from the machine controlroom is executed through Sardana macros that communicate with the pseudomotors. Those macros are used to schedule actions and perform complex motion sequences (like removing all taper before a gap motion):

- Move taper to 0
- Move gap to setpoint
- Correct motion error
- Move back taper

The insertion device elements (motor/pseudomotor) are exposed by Sardana as Tango devices [4] and can be used by other services like the archiving system, Fig. 4, or the alarm system, Fig. 5.

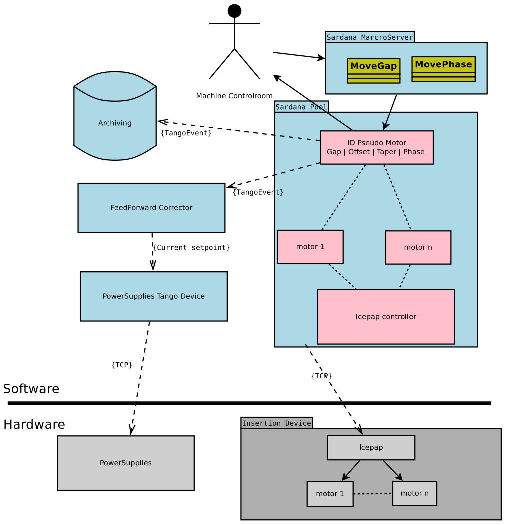

Figure 4: Insertion device motion control on the machine network.

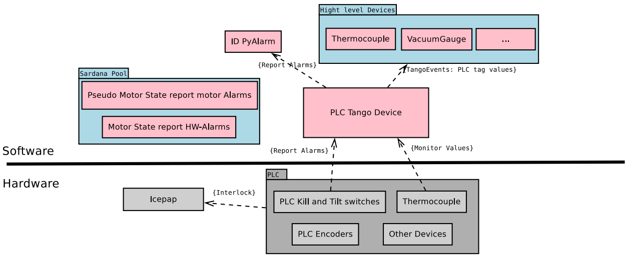

Figure 5: Safety system based on PLC.

The insertion devices are located in the storage rings and are therefore the responsibility of the machine division. The machine controlroom has priority on the ID control system and takes care of alarms and other issues. The controlroom can lock the insertion device and block all motion queries from the beamline side. An expert GUI, Fig. 6 and Fig. 7, allows the machine controlroom to get an overview of the entire ID system (motion, alarms, vacuum ...) and it is implemented based on the MAX IV svgsynoptic [5].

Alarms

All PLC alarms are exposed as tags and by a Tango device, Fig. 7. Those alarms are reported on the machine alarm system through PyAlarm.

The PLC is also in charge of monitoring some diagnostic equipment inside and around the insertion device (reporting temperature, pressure etc) that are exposed in the control system as FacadeDevices [6]. Those high level Tango devices are built on top of the Tango PLC device. This Tango device manages the PLC communication bandwidth and pushes Tango events to the high level device on each update. The high level devices are just a collection of PLC tags (like alarm, state, setpoint, monitored value etc) referring to the same physical equipment.

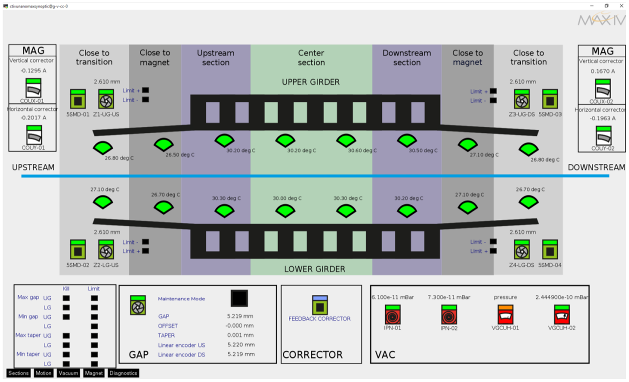

Figure 6: GUI available to monitor IVU status on the machine side. Invaluable when an alarm is activated or test and tuning is needed.

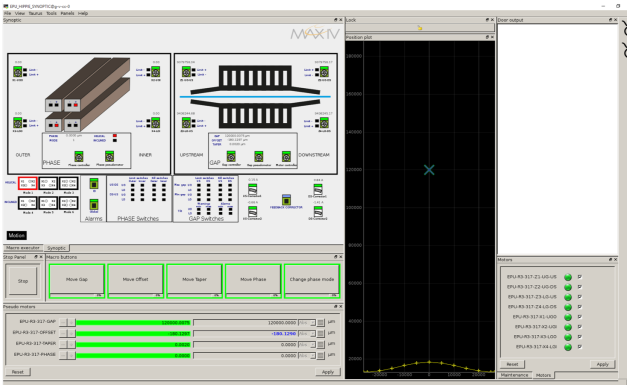

Figure 7: GUI available to monitor EPU status on the machine side.

Motion Envelope Limitation

To avoid overheating due to excessive generated radiation in the EPUs, some phase and gap combinations are forbidden. The PLC system reads absolute encoders measuring the critical axes and disables all motors if the system enters in an area defined by a motion envelope.

To avoid triggering the PLC system, before a motion, the Sardana macros check for motion envelope violation, Fig. 8. Those macros take in consideration both setpoint and motion path and can open the gap before a phase shift (and close it back after) to assure a safe phase motion.

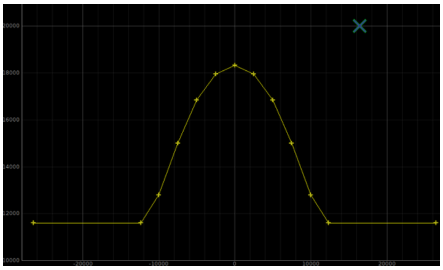

Figure 8: Phase vs Gap. The yellow curve defines a motion envelope. Motion is allowed only above this operational envelope. It is also not allowed to cross this envelope.

Feed Forward Beam Path Correction

A feed forward Tango device subscribes to the Sardana pseudomotor's position attribute (gap and phase) events. Each time one axis is moving, Sardana publishes a Tango change event. On each event, the feed forward Tango device calculates the new current setpoint value for the corrector coil power supplies, based on a lookup table.

This look up table is calculated based on measurement campaigns carried out by the ID group where the impact on the beam orbit for each insertion device is characterised.

The feed forward software implementation is based on the MAX IV FacadeDevice reactive architecture and works for a storage ring injection rate up to 10 Hz.

Beamline Control

Beamlines at MAX IV run in separate networks, Fig. 9. The beamline is the main user of an insertion device and decides the beam characteristics that need to be delivered by the insertion device. The insertion device is used in the beamline scan system, it has to be seen from the beamline control system as a movable object and has to be moved synchronously with the monochromator to define the beamline energy.

A MAX IV TangoGateway [7] allows to forward Tango requests and events between two control systems in different networks making it possible to expose the insertion device functionality from the machine network to the beamline control system.

On the beamline Sardana instance, the ID is instantiated as a simple motor. Position, state and other requests are forwarded from the machine Sardana high level pseudomotors through the gateway. The device can be moved and involved in any scan through the beamline Sardana environment as a standard movable object. All beamline ID motion commands (seen from the beamline as writing to a position attribute) are in fact executing a Sardana macro (like MoveGap) on the machine control system through the Tango gateway.

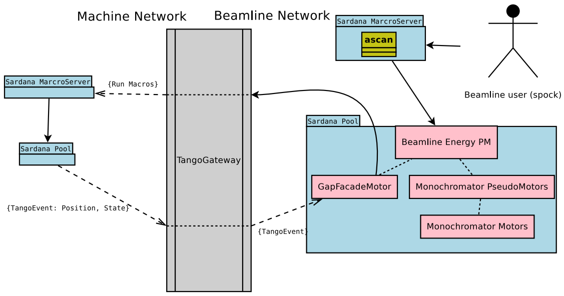

Figure 9: Insertion device motion control on the beamline network.

CONCLUSION

MAX IV has already reached a state where 10 beamlines are taking users, 4 more are in different phases of commissioning and 2 more are starting procurements.

The use of a well established in-house set of technical solutions has allowed installation, test and commissioning of a big number of insertion devices in parallel to the rest of the work for accelerators and beamlines in a relatively short period of time.

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