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SOLEIL AND SYMETRIE COMPANY COLLABORATE TO BUILD TANGO READY IN-VACUUM DIFFRACTOMETER

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Abstract

Two years ago, SOLEIL (France) and MAXIV (Sweden) [1] synchrotron light sources started a joint project to partially fund two similar in-vacuum diffractometers to be installed at the tender X-ray beamlines SIRIUS and FemtoMAX. SOLEIL diffractometer, manufactured by the French company SYMETRIE and complementarily funded by an Ile-de-France region project (DIM Oxymore) [2] gathering SIRIUS beamline and other laboratories, features an in-vacuum 4-circle goniometer and two hexapods. The first hexapod (out of vacuum) is used for the alignment of the vacuum vessel and the second one (in vacuum) for the alignment of the sample stage which is mounted on the 4-circle diffractometer (Figure 1).

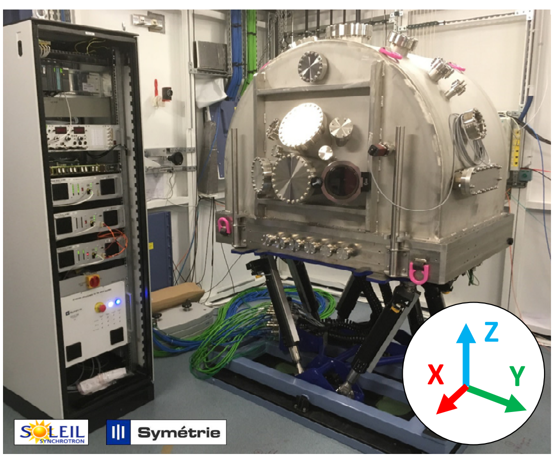

Figure 1: In vacuum diffractometer installed in the SIRIUS beamline experimental hutch with its electronics rack

In order to efficiently integrate this complex experimental station into SOLEIL control architecture (based on TANGO [3] and DELTA TAU [4] motion controller), SOLEIL and SYMETRIE [5] have worked in a close collaboration. SYMETRIE used SOLEIL developments and added to it its expertise in hexapods, motion control, and metrology. Multi-axial synchronization in the diffractometer subsystems is a key issue in this work and also opens up future possibilities in terms of improvement of the sphere of confusion thanks to corrections done by the sample stage alignment hexapod. This paper details the organization of this collaboration on the electronic and software control system.

A detailed description of the instrument mechanics, geometry and scientific applications will be the subject of a future work.

SIRIUS BEAMLINE DIFFRACTOMETER

SIRIUS takes advantage of the best energy range of the SOLEIL synchrotron ring between 1.2 and 13 keV in order to provide a tool for structural study to several communities of condensed matter.

The beamline, mounted on an HU36 undulator source and provided with two monochromators, is suitable of performing different x-ray characterization techniques such as: grazing incidence x-ray diffraction (GIXRD), small angle scattering (GISAXS) at fixed energy, and anomalous x-ray diffraction (AXD) and spectroscopies (XAFS, DAFS) in energy scans [6, 7].

Until 2015, the beamline has been equipped with two endstations (six-axis tower and kappa-head diffractometers) for hard x-ray studies of soft and hard condensed matter, respectively. However, no proper in vacuum instrumentation for fully exploiting the lower energy range of the undulator spectrum was available. The in-vacuum diffractometer project was thought to fill this lack. In fact, there is a great interest in performing resonant diffraction studies in the tender x-ray range, where the absorption edges of several chemical elements are located. These elements are common constituents of advanced materials used for technological applications such as functional oxides, III-V semiconductors and light metallic alloys.

The diffractometer is composed of three motion subsystems: The JORAN hexapod at the bottom (carries the system with the vacuum vessel), and a 4-circle in-vacuum diffractometer which is itself equipped on one of its circles of a with an in-vacuum BORA hexapod. The JORAN hexapod is used to align the center of the diffractometer according to the x-ray beam in the vertical (Z) and transverse (X) directions. It is also used as a 5th circle along the vertical (Rz-axis) which is synchronously moved with the 4-circles diffractometer. The BORA hexapod aligns the sample stage.

CONTROL REQUIREMENT

SOLEIL Motion Interface for TANGO Architecture

The diffractometer control is implemented with respect of the architecture defined in the so-called REVOLUTION project [8]. It is based on the DELTA

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TAU Powerbrick controller which is integrated and supported in the SOLEIL standard. It offers powerful computing capacity, multi-axis synchronization, encoder processing, virtual/operational space control through kinematic equations, non-linear trajectories, built-in software PLCs (programmable in Power PMAC script and/or C language) etc.

In order to permit a friendly integration in the TANGO framework, SOLEIL developed standard functionalities for the hardware low-level configuration and a standard embedded software. This approach guarantees a system delivery that is easy to use and maintain in normal operations.

Tango interfaces (Figure 2) for Delta Tau controller “ds_PowerPMAC" include the following set of devices:

- Device **PowerPMACBox** for the controller and general data.
- Device **PowerPMACAxis** for driving physical axes.
- Device **PowerPMACComposedAxis** for driving composed virtual axes (one device/CS).
- Device **RawDataViewer**, a diagnostic tool providing read-only raw firmware data of Power PMAC for specified axis.

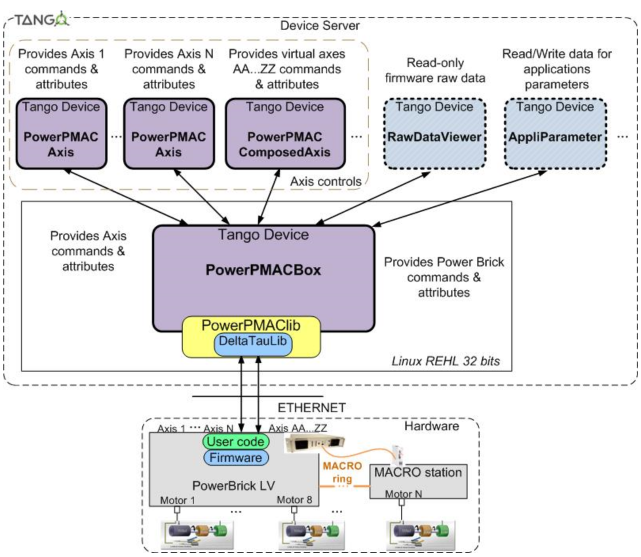

Figure 2: Software architecture overview, from TANGO to Power PMAC.

The collaboration with the SYMETRIE Company to develop instrument control was established on this principle: SOLEIL provides the high-level TANGO interface and low-level layer embedded in the controller. SYMETRIE (Figure 3) integrates and connects their kinematic routines to the TANGO interface, adding specific configurations and code for the hexapods and the diffractometer.

HARDWARE ARCHITECTURE

The implemented architecture (Figure 4) from SYMETRIE is composed of a Power Brick controller for each subsystem: the JORAN hexapod, the 4-circles diffractometer, and the BORA hexapod.

Temperatures of in-vacuum motors are monitored by a dedicated PLC which interlocks the motion controllers in case of overheating.

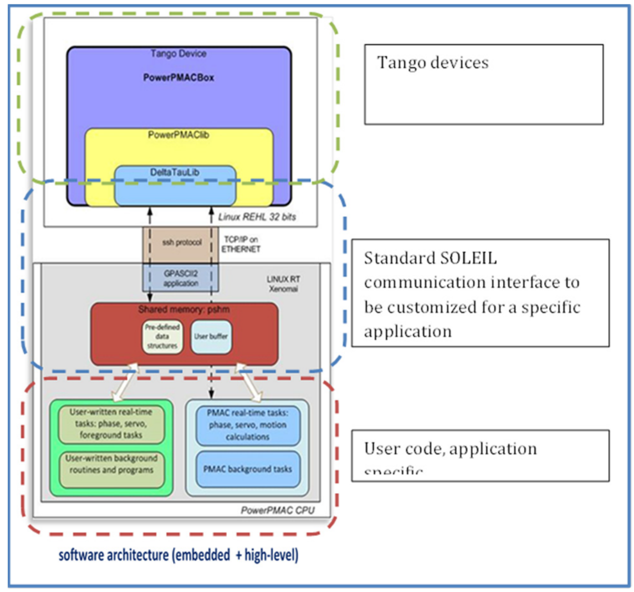

Figure 3: Power PMAC software feature.

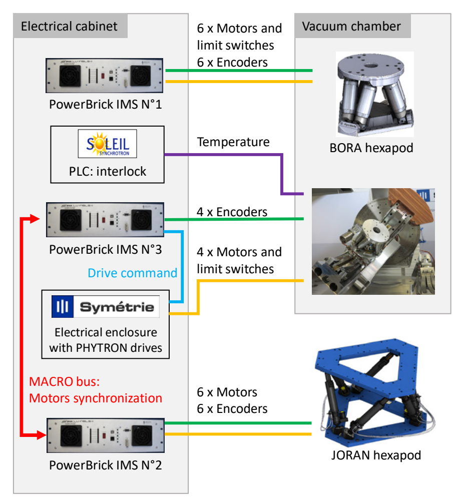

Figure 4: Hardware architecture.

The last circle of the 4-circles diffractometer has infinite rotation ability. A vacuum slipping ring is used to convey electrical signals and powers to the BORA hexapod and to the sample.

In order to enhance automatic alignment and reach the best possible SOC (Sphere Of Confusion), the diffractometer and the JORAN hexapod controllers are both synchronized by a MACRO bus. MACRO is an open protocol, for real-time motion and a machine control bus, which was developed by DELTA TAU. The MACRO bus on the Power Brick controllers permits to synchronize multiple axes from multiple control- systems.

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TANGO INTERFACE

Two TANGO devices are used to interface the Power PMAC controller for this application. The first one, named **PowerPMACBox** device, has a fixed interface optimized for motion. The second one, name **PowerPMACdataviewer**, is flexible and allows any variable exchange with the controller.

Those devices allow the configuration and the control of singles axes and composed axes. A "composed axis" is a group of operational axes, to which can be associated with simple or complex kinematic models (that act on one or several motors) in the Power PMAC controller.

SYMETRIE used a VirtualBox running SOLEIL TANGO packages providing Device Server, Scanning tools, etc…). Power PMAC devices were used to test the work done on the controllers. SYMETRIE directly delivered the TANGO devices configuration files to SOLEIL.

The PowerPMAC device (Figure 5) can be used to read positions and start movements, to configure speed and acceleration, or to launch homing sequences. On composed axes; operational linear moves are realized using high frequency path interpolation for motor synchronization. Speed can be configured in its operational space to be constant or it can use the fastest possible speed (under the constraints of each motors maximum speeds and accelerations); this is done thanks to the look-ahead feature of the DELTA TAU controller.

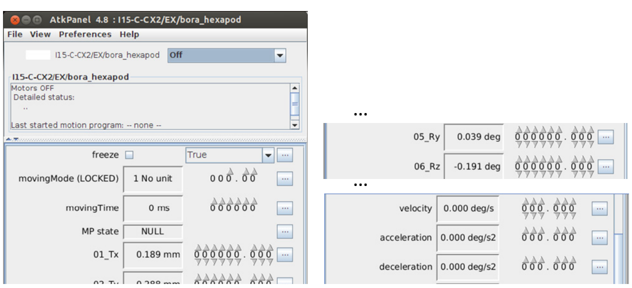

Figure 5: SOLEIL TANGO Power PMAC device.

SYMETRIE used dataviewer devices (Figure 6) to give the possibility to modify the hexapods coordinate systems.

An operational position is fully described by the position and orientation of a frame, relative to a reference frame. For SYMETRIE hexapods, the operational position is defined when "platform" coordinates are transformed into "machine" coordinates. The SYMETRIE software allows customers to move between these two coordinates systems CS.

In addition, "machine" coordinates can be transformed to another fixed so-called "user" CS, and the "platform" CS can be transformed into a so-called "object" CS. The commanded and read positions become the position of the "object" CS in the "user" CS, which are all implemented into the controller. Change of coordinate system allows for example the adjustment of the center of rotation of the BORA hexapod after a sample stage change.

In standard use two composed axes are used: one for the BORA hexapod, and one for the group "4-circles + JORAN hexapod". Others single- and composed axes were created for maintenance purposes.

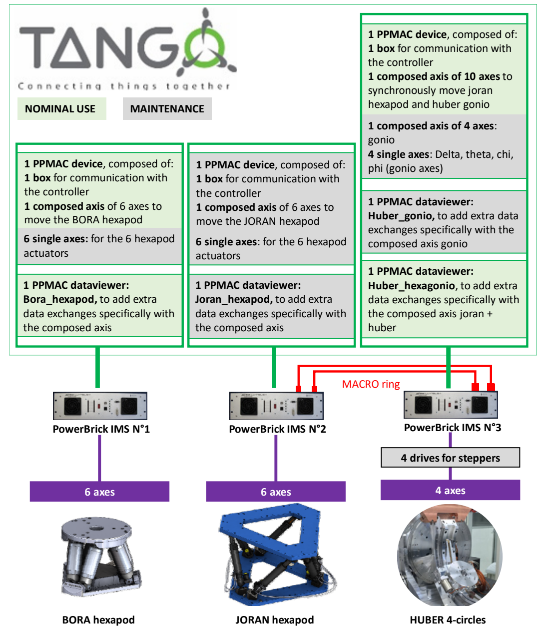

Figure 6: TANGO devices.

CONTROLLER EMBEDDED SOFTWARE

SOLEIL developed its Power PMAC embedded interface in 2014. The software has already been deployed on the SAMBA beamline for their monochromator.

The main guideline on this new project was to integrate SYMETRIE hexapods into SOLEIL developments. The delivery to SOLEIL is an open-software project with a SYMETRIE pre-compiled hexapod library. This solution allows for system evolutions and independence in SOLEIL, and to protect SYMETRIE knowledge. It was made possible by the great flexibility of the DELTA TAU controller which SYMETRIE has been using for its hexapods since more than 15 years.

Each of the three systems were first independently implemented on their individual controller. Various hardware were interfaced: incremental and absolute BiSS encoders, and stepper motors, using Power Brick drive stages and external drives. Homing and limits switch functionalities when needed.

SYMETRIE built a library (Figure 7) having interfaces compatible with SOLEIL development. That library is made of few functions which manage the kinematics, the hexapod moves pre-validation, the coordinate systems changes, some real-time security verifications. Few evolutions to SOLEIL development were proposed, jointly validated and implemented.

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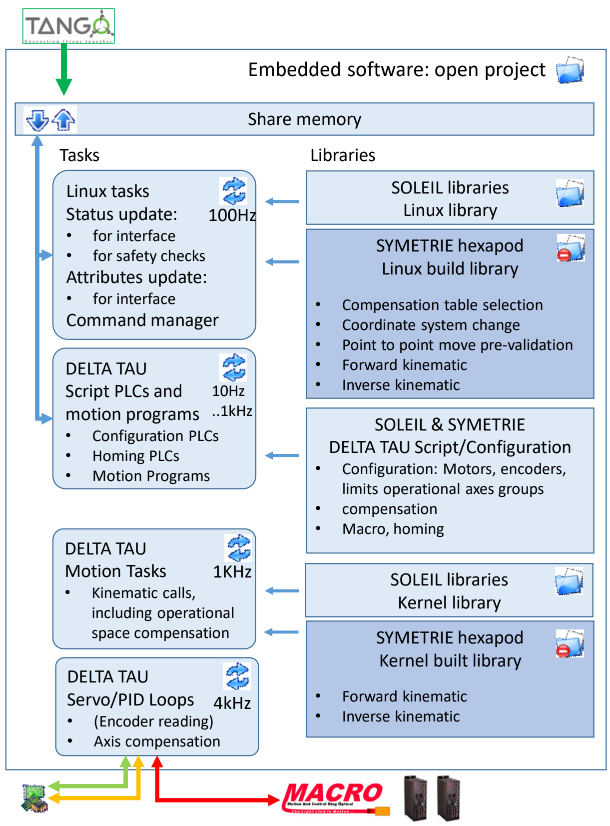

Figure 7: Controller embedded software.

The project requested the synchronization of JORAN hexapod Rz axis with the 4-circles. A single operational entity was created grouping the 4-circles and the JORAN hexapod. This was made using the MACRO bus. The 4-circles controller control the JORAN hexapod motors in torque mode, sending torque commands, receiving the encoder positions and exchanging various security variables, all this at 4kHz. Having all those axes in a single operational entity allows synchronized interpolated moves, common acceleration and deceleration phases, and common stops. In MACRO use, only current loops are enabled on the JORAN hexapod Power Brick, being reduced to a six drives station.

SYMETRIE, combining metrology expertise to its motion expertise, did the metrology qualification of the diffractometer. To improve the accuracy of the system, compensation tables were implemented in the controller. Accuracy compensation tables for the 4-circles and operational accuracy and cross-coupling compensation tables for the JORAN hexapod. The operational moves are interpolated at 1 kHz, permitting a smooth operational compensation along the path. Compensation tables permit to reduce the errors to levels close to the accuracy of the measurement instrument or to the repeatability of the positioning device.

Possible Evolutions

The next step is to improve the SOC (sphere of confusion) of the diffractometer by compensating the 4-circles errors (mechanical defaults, crossed motion bending/deformation, cross-coupling) using the BORA hexapod. It can be done along the operational axes path by grouping the 4-circles and the two hexapods in a single operational entity with the help of the MACRO bus. Moves will be synchronized and interpolated allowing for compensation adjustments along the path. See the pink frames on Figure 8.

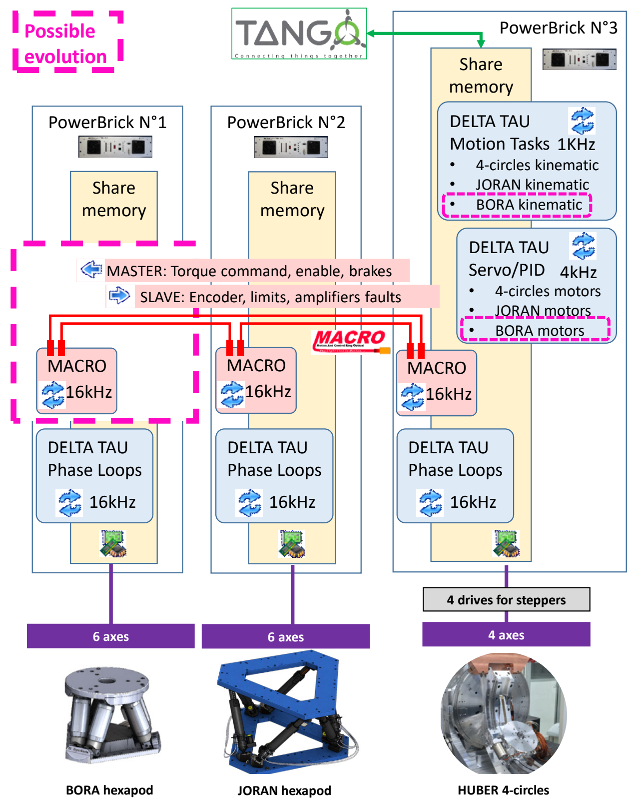

Figure 8: MACRO allow motors control from a single controller – BORA hexapod could be added.

CONCLUSION

SOLEIL is convinced in their choice of the DELTA TAU controller for its systems requiring complex control. It also confirms that the software architecture is flexible and well adapted for collaboration, allowing for an easy integration of third party kinematics while maintaining the same interface.

The strong collaboration between SOLEIL and SYMETRIE permitted an optimum integration of SYMETRIE hexapods in SOLEIL TANGO developments. SYMETRIE was able to deliver an open software project to SOLEIL, allowing evolution and independence for SOLEIL and protecting SYMETRIE knowledge. Synchronization of the JORAN hexapod and the 4-circles diffractometer was needed when using the JORAN hexapod Rz- axis as a 5th axis for the diffractometer. This synchronization was successfully conducted using the MACRO bus to command JORAN hexapod motors from the 4-circles controller and by grouping the JORAN hexapod and the 4-circles in a single operational entity.

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Thanks to the collaboration with SOLEIL, SYMETRIE is now able to furnish a ready-to-use, TANGO controlled, hexapod system.

The diffractometer factory acceptance tests were successfully carried out at SOLEIL which involved: the mechanical integration on the beamline, the metrology constraints, the vacuum quality of the chamber, the project management and collaboration were successfully achieved. The instrument will be commissioned with the synchrotron beam by the end of the year 2017.

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