REVOLUTION PROJECT: PROGRESS IN THE EVOLUTION OF SOLEIL MOTION CONTROL MODEL*

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Abstract

SOLEIL is a third generation synchrotron radiation source located near Paris in France. REVOLUTION (REconsider Various contrOLler for yoUr motion) is the motion controller upgrade project currently in progress at SOLEIL. It was initiated to maintain the facility operations by addressing the risk of hardware obsolescence in motion control but at the same time making room for complex applications requirements to face new high performance challenges. In order to achieve these considerations, SOLEIL's strategy move was to go from a single controller for all applications to two motion controllers. A first Controller GALIL DMC-4183 was chosen to succeed the previous version DMC-2182. Both controllers can be integrated in the existing architecture with little hardware and software adaptation enabling full compatibility with the existing architecture. A second controller, Delta Tau Power Brick, has been selected as a HIGH PERFORMANCE solution providing advanced functionality.

The CLASSIC controller upgrade is about to be completed and the integration of Power Brick into the SOLEIL control system is ongoing. The system complexity is abstracted by embedding processing functions into low-level code and giving end-users a simple high-level interface. The work done to structure the interfacing and standardization of the controller are detailed in this paper.

CONTEXT OF REVOLUTION AT SOLEIL [1]

Motion Control Status and Upgrading Motivations

SOLEIL needs to upgrade its standardized GALIL motion controller in order to address two challenges: First, the current motion controller used in SOLEIL is dated and in risk of being discontinued and we must have an updated product before this happens. Nevertheless, this is not expected to occur in the next few years. Secondly, new motion control applications demand a higher performance and more advanced features that can not be reached by our current controller.

Strategy: Change Model

To achieve the next three goals of "Increasing performance, maintaining operational continuity, and controlling overall cost", SOLEIL decided to replace the current model of a "single and universal controller" by a model with two kinds of motion controllers:

- CLASSIC motion controller, mainly used and suitable for "simple and classic" applications. This controller is fully compatible with the existing hardware and software motion control architecture.
- HIGH PERFORMANCE controller, used in few cases, suitable for "complex and fast" applications. The hardware and software motion control architecture is designed to be close to the existing architecture for the CLASSIC controller.

CLASSIC CONTROLLER EVOLUTION

The GALIL DMC-4183 controller was chosen to succeed the current Galil DMC-2182. Its implementation needs some hardware and software developments which are currently being done to make it compatible with current architecture. On the software aspect: a new firmware was developed by GALIL which includes the new "Continuous Closed-Loop on Stepper motors" feature. It was validated by SOLEIL by an operational application done on the monochromaters of LUCIA and TEMPO beamlines. To use this feature, a new microcode (embedded code) was developed and validation tests are ongoing. For the hardware: in order to use the current ControlBox rack (same size, same pinouts), an interface board (MIG-4121) has been developed which adapt the DMC-4183 to the internal pinout of the ControlBox rack. The integration in the rack has been validated and is now operational.

HIGH PERFORMANCE CONTROLLER STANDARDIZATION

Controller Product

Delta Tau Power PMAC in the Power Brick LV-IMS format was selected for the new "HIGH PERFORMANCE" solution after a long evaluation process.

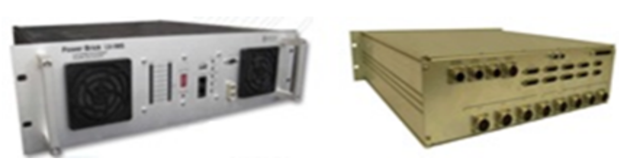

Figure 1: Power Brick LV-IMS.

Power PMAC is a general-purpose embedded computer with a built-in motion and machine-control application which offers: powerful computing capacity, multi-axis synchronization, encoder processing, virtual control through

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kinematic equations, non-linear trajectories, built-in software PLCs (programmable in Power PMAC script and/or C language) etc. Moreover, around Delta Tau products there is an international user community in large research facilities.

The Power Brick LV-IMS rack (see Figure 1) is now available with a SOLEIL standard compatible connectivity for motors and encoders. It comes with the configuration of a Power PMAC CPU and 8-axis integrated amplifier circuits for 2-phase and 3-phase motors direct-drive. The number of axes can also be expanded through a MACRO fiber optics network. As an option, it can be configured to support different encoder feedback protocols among a wide variety of choices.

Control Architecture

For reasons of consistency and usability we intended to keep a control architecture as close as possible to the existing one. Considering the performance benefits of the product, most process functions are embedded into low-level to abstract the system complexity for the high-level software. In order to make the controller easy to use and maintain in normal operations, we developed some standard functionalities for the hardware low-level configuration and in the embedded software.

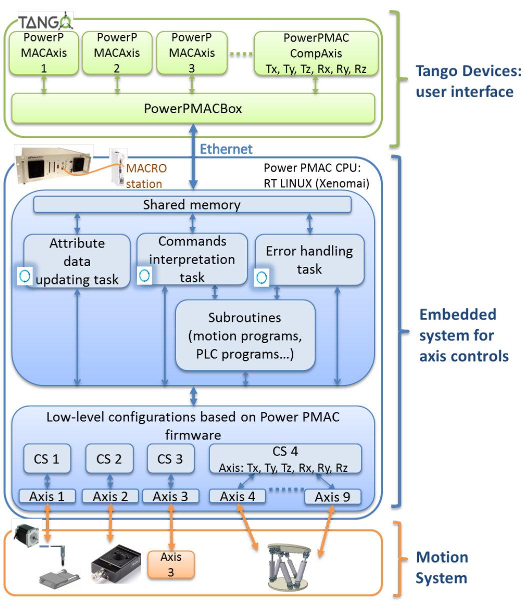

Figure 2: Power PMAC embedded system structure with an example of motion system application.

High-level Software for User Interface

In order to structure the end-user interface, the software high-level architecture shown in Figure 3 has been developed. The software consists of Tango devices for axis controls and general rack controls. The rack controls communicate over the "PowerPMAClib" and "DeltaTauLib" libraries.

The Tango device interface for the new HIGH PERFORMANCE controller is designed to be very similar to the standard CLASSIC controller. A single Device Server

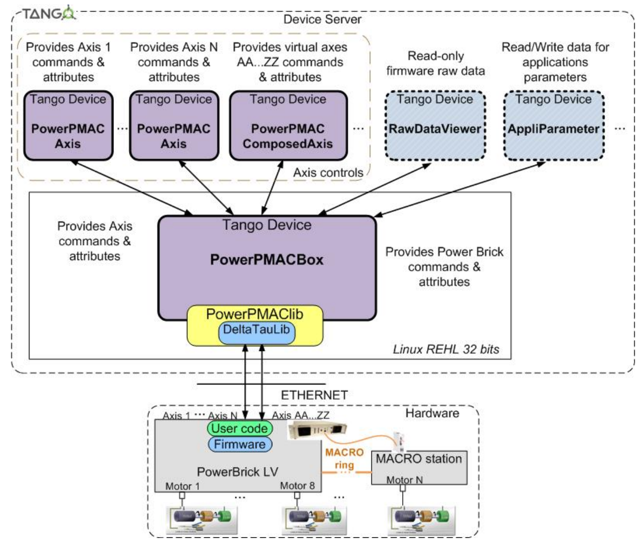

Figure 3: High-level software architecture.

"ds_PowerPMAC" including the main set functionality is composed with the following devices:

- Device **PowerPMACBox** for the controller and general data.
- Device **PowerPMACAxis** for driving physical axis.
- Device **PowerPMACComposedAxis** for driving composed virtual axes (one device/CS).

To complete the functionality supply, some devices are planned to be realized in the near future:

- Device RawDataViewer, a diagnostic tool providing read-only raw firmware data of Power PMAC for specified axis.
- Device AppliParameter, a tool providing read and write data of the controller for users to parametrize their application-dedicated variables.

The Tango devices access the Power PMAC level through "PowerPMAClib", which encapsulates "DeltaTauLib". "DeltaTauLib" is supplied by Delta Tau to provide access to the firmware and embedded "user" data via Ethernet [2]. The "PowerPMAClib" library, developed by SOLEIL, presents in its interface the access to general controller functions (e. g. connection, status, temperature, operating time, reset etc.) and the axis control functions (e. g. position, speed, stop etc.). Within axis controls, the library makes the link to the data structures stored in the shared memory of the controller for data exchanging and command settings. The information in the data structures are accessed and updated from the embedded programs in parallel from the Tango devices.

Embedded System Structure

Power PMAC uses Linux OS with the Xenomai preemptive real-time kernel which runs a single real-time application to handle tasks of different priorities [3].

In order to better manage the controller in an operational condition with different motion system applications, we implemented a generic Power PMAC project independently of the application system which is organized in 3 layers:

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an embedded software layer for Tango axis control interface, a subroutines layer for functional sub-programs, and a hardware layer for low-level configurations (see Figure 2).

Embedded software layer: interface for Tango axis control For physical- or virtual- axis control: all commands, property settings, attribute reading/writing, and state/status requests from the Tango software go through the embedded software layer to access the firmware. Via predefined indexed data structures in the shared memory of the controller, this layer acts as an intermediate between the Tango software and Power PMAC firmware. Data structures are shown in Figure 4.

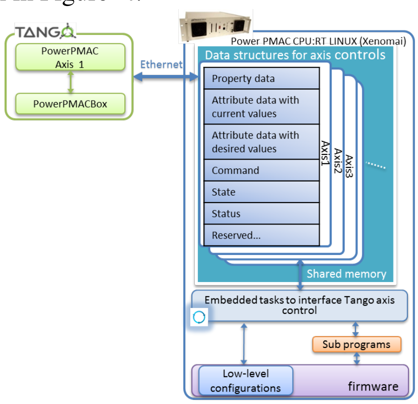

Figure 4: Predefined indexed data structures in Power PMAC shared memory for Tango axis control.

The features of this layer are:

- Interpretation of commands provided by the Tango device and that they only run if operating conditions allow.
- Attribute data updating: for exchanging high-level attributes with low-level parameters, parameters being changed only within allowed conditions.
- Error handling: setting flags in the state/status variables when certain errors/warnings occur.

These features are realized by 3 different tasks running in 2 threads with separately adjustable cycle times. One single thread is used for the tasks of interpretation and error handling. In the scope of the high-level polling frequency, this thread has higher priority than the thread used for updating data attributes.

Subroutines layer: functional sub-programs definition This layer implements some sub-programs that can be called or stopped by the software layer command request to perform a processing function or trajectory followed moves. These programs can directly use firmware functions and act on low-level hardware settings. Their execution status are continuously checked on by the interface layer for safety handling.

Some application-dedicated programs, including motion- and PLC- programs, will be defined and implemented depending on the needs. Some common programs will be part of the generic project:

- Motion programs for reference-position initialization.
- Duty cycle PLC program for motor stops within a certain period.
- Vacuum mode PLC program to itch motor current depending on the motor status (moving or stopped).
- System start-up PLC program to initialize the amplifier and reset the embedded system.

Hardware layer: low-level configurations Some typical hardware setups need to be standardized to minimize and simplify installation work. These setups have been identified of which the configuration files have been templated:

- Encoder conversion setups: Quadrature, Sin/Cos, SSI, BiSS-C...
- Motor setups:
  - 2-Phase stepper motor setup: closed Loop & micro-stepping
  - Motor setup using third-party drives with PFM signals output
  - 3-Phase brushless servomotor setup
  - DC brush motor setup

Based on the tested and validated templates, a GUI tool (see Figure 5) has been developed to automatically generate configuration files according to preselected parameters: channel number, motor type, encoder type, motor current etc. Hardware commissioning will however require a tuning process followed by manual modifications of the files. The PID regulation can be done using the Power PMAC IDE tuning tool. From then, the CS (Coordinated System)

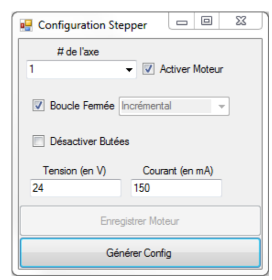

Figure 5: Hardware configuration file generator tool.

configurations will be added in the files to create the relationship between controlled axes and motors (see low-level configurations part in Figure 2). To properly benefit from the "Power PMAC CS" functionality, an individual motor is associated to a CS for physical axis controls, same as for virtual axis controls. Each CS configuration is made by a set of Kinematic forward & inverse routines.

A step-by-step procedure on low-level installation configurations and files archiving procedures for maintenance will be defined.

Integration Test Results

Unitary tests of the standardized software and hardware have been realized and validated. The integration test in the SOLEIL control system is validated with the Power Brick LV in a laboratory setting. Some details need to be finalized.

Several low-level tests have been accomplished or are ongoing on some beamline applications: DCM (double

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crystal monochromator) on PLEIADES, DCM on SAMBA, NANOPROBE (joint project between Synchrotron SOLEIL in France and MAXIV in Sweden) [4]. The integration tests are also scheduled for these Beta-tester applications.

SAMBA beamline DCM control upgrade (see Fig. 6) Currently the system is controlled by the CLASSIC solution. This upgrade aims to achieve a low-level direct energy control and thereafter a continuous energy-scan operation, which is expected to significantly reduce the experiment duration with faster execution and reduced Ethernet communication

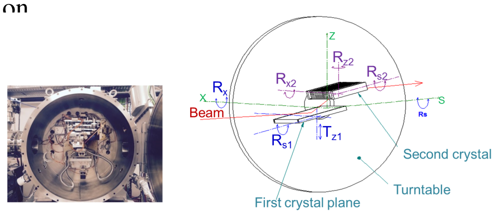

Figure 6: SAMBA beamline DCM motion system.

The control of the 7 main axes (R_x, T_{s2}, T_{z2}, C_1, C_2, R_{z2}, R_{s2}) have been installed on a Power Brick unit. It includes a DC brush and 6 steppers for which the low-level settings have been tested and validated. The kinematic equations have also been implemented to provide direct energy control, detailed as following.

Equation between E and the main axis $R_x(°)$ is shown as below, in which E is the photon energy in eV, d is the lattice spacing in Å, θ is the angle of the main axis of the monochromator R_x in °.

$$E = hc\frac{1}{\lambda} = \frac{hc}{2d}\frac{1}{\sin(\theta)} \tag{1}$$

The remaining motors need to be synchronized with the main axis to obtain the desired energy.

T_{s2} and T_{z2} are the two translations of the second crystal:

$$T_{s2} = \max(T_{s2}^{Min}, \frac{H}{2\sin(\theta)});\ T_{z2} = \frac{H}{2\cos(\theta)} \tag{2}$$

C_1 and C_2 are the positions of the two motors of the second crystal bender. As shown in the equations below, R is the radius of the crystal obtained; $\frac{1}{R}$ is the curvature. $A_{i,j}$ are coefficients:

$$C_1(\frac{1}{R}) = A_{1,0} + A_{1,1}\frac{1}{R};\ C_2(\frac{1}{R}) = A_{2,0} + A_{2,1}\frac{1}{R} \tag{3a}$$

$$\frac{1}{R} = \frac{1}{2\sin(\theta)}(\frac{1}{p} + \frac{1}{q}) \tag{3b}$$

R_{z2} and R_{s2} follow empirical correction curves. Shown in the equations below, p and q are the source to monochromator and monochromator to sample distances.

$$R_{s2} = P_n(\theta, c_{R_{s2}});\ R_{z2} = P_n(\theta, c_{R_{z2}}) \tag{4a}$$

$$p_n(\theta, c) = \sum_{i=0}^{n} c_i\theta^i \quad c = \begin{pmatrix} c_0 \\ c_1 \\ \vdots \end{pmatrix} \tag{4b}$$

Tests in low-level with the kinematic conversions have been done and integration tests with the Tango devices will be done soon. The additional functions of enabling or disabling one of the relations for test or to perform a scan, will be realized with the Tango Device "AppliParameter".

New Complementary Product

To meet the required applications when external drivers are in use, a new complimentary product Delta Tau Power Brick controller is now specified. It contains the same CPU (Power PMAC) as Power Brick LV without the built-in amplifier, providing PFM and analog signals for third-party drives. In addition, this product should be fully compatible with the CLASSIC controller in respect to cabling connectivity; an eventual control upgrade would be fairly direct and easy.

The same tool settings as well as skill-sets would be used to configure the new controller. It is expected to be integrated in the SOLEIL control system without extra development.

CONCLUSION

The new strategy of moving from a model with a single universal motion controller to a model with two specialized controllers is being implemented. Operational continuity is ensured with the new CLASSIC controller while at the same time improving some functionalities. The chosen HIGH PERFORMANCE controller, Delta Tau Power Brick, is very powerful and versatile which allows it to handle high performance systems.

The main challenge with this controller is to offer the high-performance of the Power Brick and the DMC-4183 to the end user while still keeping an easy-to-use interface. Both controllers are now ready to be used for simple functionalities and the next step will be to train the electronic group to have the necessary skill-sets to maintain these products in operation. Advanced functions, such as compensation tables and remote managing of motion programs, will be improved. The HIGH PERFOMANCE controller will bring value to different control upgrade applications in projects such as monochromator, Flyscan, Nanoprobe and Goniometer.

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