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A new EtherCAT based control/automation scheme for the BElChem DCM beamline

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Abstract. To align BESSY II with the broader BESSY II+ facility upgrade plan, a new generation of control systems hardware and software is necessary [1]. The existing end-of-life hardware will be gradually replaced with modern state-of-the-art tools.

In the initial phase, the new Berlin Joint Lab for Electrochemical Interfaces (BElChem) hard x-ray beamline at BESSY II will undergo equipment upgrade, starting with the installation of new motion control hardware. The beamline includes a double crystal monochromator (DCM), and two adjacent mirror chambers, which comprise 20 motor axes, a selection of different feedback and temperature sensors and a piezo driver. The selection of the new hardware is based on the integration of all necessary components into a unified physical control system, while ensuring the required precision and velocity for beamline operation.

Previous prototypes involving the EtherCAT interface have delivered positive results, prompting its adoption in this project. Various EtherCAT devices are considered during the evaluation process. The design of the EtherCAT-based control system will be presented and discussed.

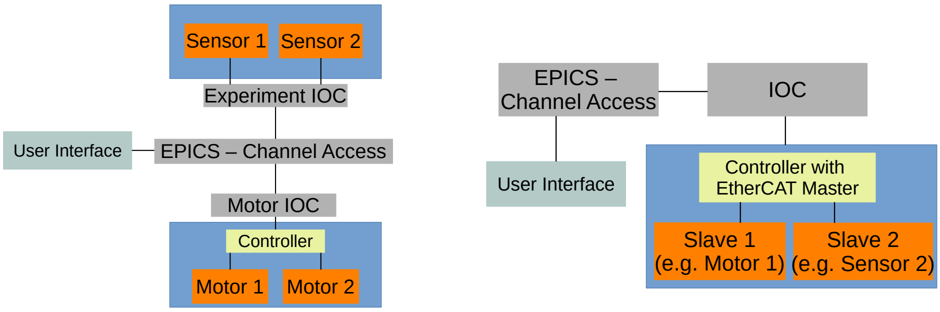
1 Introduction

The ideas proposed in this paper will be implemented at the BElChem DCM beamline at BESSY II. In the long term, this will be a prototype for the standardisation of the control systems in the current beamline infrastructure. This work is undertaken as part of BESSY II+ modernisation projects, aimed at modernizing user operation at BESSY II. In this paper, the improvement of the existing control system structure is discussed. This involves a centralisation of computation and control in a control system and consequently a simplification of the overlaying software structure. For future applications the system has to extendable and able to fit varying requirements.

2 Structure

At BESSY II the Experimental Physics and Industrial Control System (EPICS) has been in use for a considerable time and therefore should be retained. The current state of the control system structure is described by Balzer *et al.* [2]. Additionally, on the side of experiments EPICS Input/Output Controllers (IOC) exist, which interact with the control systems. Figure 1a gives a rough overview of a deployment of multiple IOCs on a beamline.

A disadvantage in this scheme is the delay in communication. Consider the situation shown in Figure 1a, where data flows from "Sensor 2" to its "Experimental IOC" for processing. This data is sent to the adjacent "Motor IOC" for processing and movement of "Motor 1". Forwarding of data is done via EPICS



(a) existing structure (b) intended structure

Figure 1: EPICS existing and intended structure

channel access, which utilises Ethernet or a serial interface. In this process, delay is mostly added by the communication between IOCs. Ethernet, which is mostly used, is designed for reliable data transfer with the trade-off in latency [3]. The used soft IOCs are deployed on virtual machines, which operate and process data in a non-realtime environment (with an update rate of 10Hz and less).

To improve the beamline controller structure, shown in Figure 1a, a different approach will be tested as illustrated in Figure 1b. In order to remove the communication delay and have an environment which is real-time capable for time critical tasks (synchronised movements of axis and devices), the computational tasks from the IOCs will be put inside the controller. This paper proposes an idea to utilise a controller which includes an EtherCAT master [4]. This offers the possibility to extend the controller by functions and devices which are needed for local operation. It involves also the possibility to connect other beamline systems to the same real-time environment and do not have a need for further dedicated IOCs.

3 Control System practical application

After testing several alternatives the Omron Programmable Multi-Axis Controller (PMAC) [5] with EtherCAT functionalities are used to control the DCM and the mirror chambers.

3.1 Hardware

The BElChem DCM system consists of 20 motor axes and also includes a piezoelectric actuator, strain gauges, potentiometers and temperature sensors (PT100, thermocouple). Two types of PMAC offered by Faraday Motion Controls [6] will be used in the setup. The Power Brick LV IMS, which is in a 19" package and contains all necessary electrical support circuitry and the FMC1040 EtherCAT Motion Controller, which consists of a quad core computational unit without additional hardware (motor driver/IO), will also be utilised.

3.2 Selection Process

The decision to use the PMAC is based on an evaluation process. In this process a unified test setup was utilised, which is described by David Kraft [7]. The mechanical setup consists of a fixed selection of motors (Phytron ZSS 57.200.2,5-FD, Faulhaber AM1524R025055, ACT 17HM5417) and an absolute encoder (Hohner SMRS10-13124512R-19 with 2^{19} counts). On the software control side, all systems were fitted with an EPICS motor record based support and a corresponding IOC. The testing process answered different questions regarding handling and functionality.

With the Power Brick LV IMS it was possible to cover the mandatory positioning within 1 to 2 arc seconds (based on Bragg equation, equal to 4 to 5 motor full steps) in open loop and a simple closed loop setup.

The result in Figure 2 illustrates the position deviation δ_n in encoder steps from a requested position x_n. The requested position and the error are calculated by (1) and (2) respectively.

$$x_n = \begin{cases} \Delta = 524288 \ (2^{19} \text{ encoder counts}), & \text{if } n \text{ odd} \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

$$\delta_n = x_n - y_n \qquad \text{where } y_n \text{ is the measured position value} \tag{2}$$

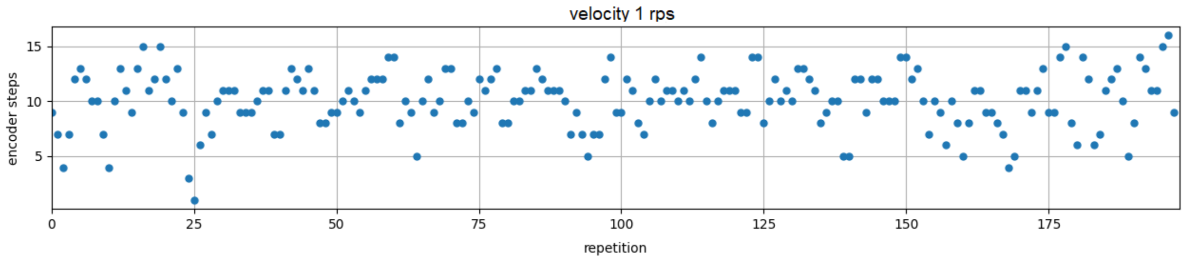


Figure 2: position deviation after positioning tests in closed loop for Power Brick LV IMS and ZSS 57.200.2,5 following equations (1) and (2); position deviation shown in raw encoder counts for 200 repetitions

In the context of micro steps, the resulting deviation in Figure 2 lies within 3 micro steps. In the used test setup 5.13 encoder increments are equal to one micro step. The conversion factor of 5.13 results from a stepper motor resolution of 200 motor full steps per revolution, a controller resolution of 512 micro steps per one motor full step, and an encoder resolution of 2^{19} increments per revolution.

During an additional open loop test with 9000 repetitions, a biggest error of 7 micro steps was observed.

Also the creation of coordinate systems is possible using the PMAC. A coordinate system enables simultaneous movements of several axes. Each axis can be configured to follow an arbitrary trajectory.

The programming can mostly be done in text scripts, that are easy to adapt for other axes. In case of hardware replacement, a program can be loaded without the need for an IDE. EtherCAT is part of the controller. It can be delivered in a 19-inch rack size package. The required EPICS motor record support is already available.

3.3 Implementation

The Power Brick LV IMS will be used in a configuration with 8 internal axes at the DCM. This is because the internal motor drivers are capable of delivering the required precision of 1-2 arcsec or less. The included PMAC algorithms (PID control) can be used to configure and deploy closed loop operation and improve the positioning. A configuration with additional external drivers will not be used.

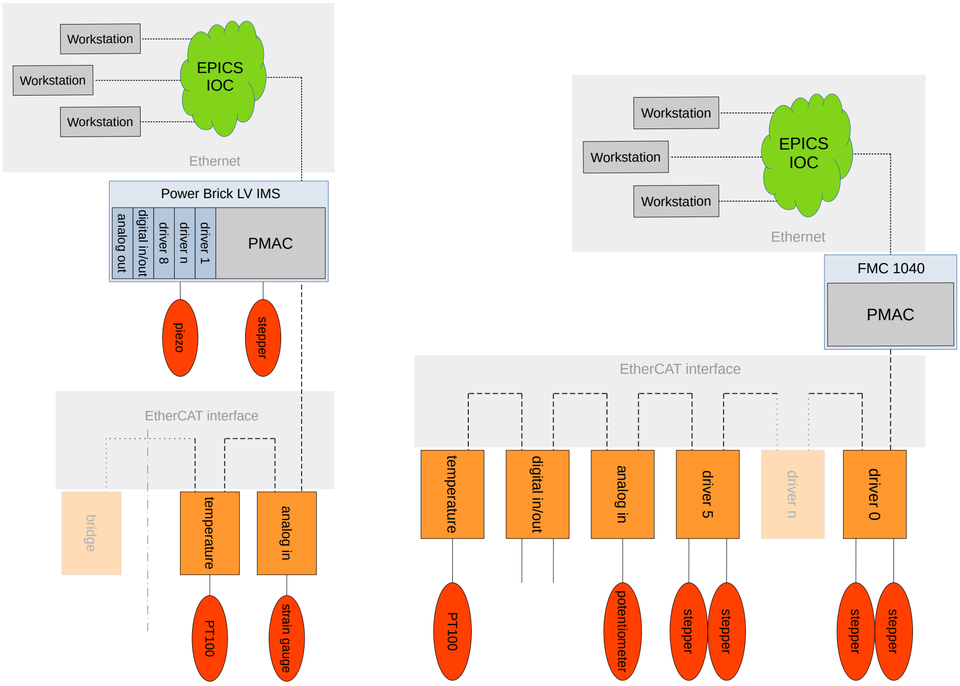
During the validation process a processing problem in the laboratory setup was noticed. It was observed that an intentionally created fault on an external driver was either too late or never indicated inside the PMAC (by a status flag). Since the error was indicated in the EtherCAT variable but not in the PMAC flags. It seemed there is an internal conflict between the processing of internal and external drivers.

This behaviour was not observed for the FMC1040. Therefore it will be utilised for the two mirror chambers and two extra DCM axes as these do not require such precise positioning. Therefore, a more cost effective motor driver in terms of precision and setup effort can be selected. For simpler applications like temperature sensors and strain gauges and their integration into the PMAC, Beckhoff offers suitable modular IO hardware terminals.

The Setup of two mirror chambers and DCM, involves four coupled movement axes, each of which is represented by its own coordinate system. As a consequence, each couple is implemented in the same controller. The DCM contains three main axes for energy selection, which needs to be in one coordinate system for the coupled positioning. Two axes are required for the bending of the second crystal, which are monitored by two strain gauges. A synchronous movement and positioning is crucial for these axis, otherwise damage to the crystal will occur. The two mirror chambers contain one tripod each, which have to be handled in their own coordinate systems.

Therefore we have two coordinate system for the DCM (implemented in Power Brick LV IMS) and one for each mirror chamber (implemented in FMC1040). In total, 11 axes are implemented in the two controllers: this is three axes for the DCM coordinate system , two axes for the crystal bender coordinate system and one coordinate system for each mirror chamber (each with three axes). The 9 remaining axes are not part of coupled movements. The resulting hardware structures around the PMACs are illustrated in Figure 3a for the Power Brick LV IMS and figure 3b for the FMC1040.

For the EPICS integration of PMACs into a single IOC, Diamond Light Source has already developed free software [8] which utilizes EPICS motor record [9].



(a) DCM (b) Mirror Chambers / DCM

Figure 3: Control System Scheme

4 Conclusion

4.1 Inference

In different tests, it was possible to approve reliable working configurations of hardware.

The PMAC were successfully connected with EtherCAT slave devices from Beckhoff. This involves types like EL3214 and EL3751 for obtaining temperature and strain gauge values, respectively and the TE2-090-07 stepper motor driver from Copley. Promising results have been achieved, for the configuration and usage of all required motor types. With the help of a test bed [7], operation in open and closed loop could be reliably established. The results obtained from these test setups, which were performed in a laboratory environment, have proven promising with regards to beginning the build up process of the control system on the BElChem DCM beamline during the next months.

4.2 Outlook

Further enhancements for other beamlines are already thinkable. Additional EtherCAT based drivers can be added, which are not integrated inside the PMACs motion system (without the mandatory DS402 profile). This can be done for axes, which do simple back-and-forth movements only. It avoids the need for further axes licenses and more expensive drivers.

Undulator based beamlines also have the need for synchronised motion between the monochromator and undulator. Here an approach of synchronisation with an EtherCAT bridge, directly between controller or with a supervising layer, seems feasible.

In order to further improve the communication between the EPICS IOC and the controller (reduction of delay and disturbance by congestion). There is the idea to integrate the Linux based EPICS IOC into the PMAC controller, since the PMAC itself is using Linux as an operating system.

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