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CONTROL SYSTEM FOR HESEB BEAMLINE AT SESAME

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Abstract

The HElmholtz-SEsame Beamline (HESEB) is a state-of-the-art soft X-ray beamline donated by Helmholtz research centre that was successfully installed and commissioned recently at Synchrotron-light for Experimental Science and Applications in the Middle East (SESAME). The control system design and implementation, which includes controlling low-level up to most sophisticated devices, has been done by SESAME's control engineers. This paper describes the design and implementation of the control system required to deliver the complete functioning of the beamline as well as the safety system including its measures put in place to protect the beamline's equipment and users.

INTRODUCTION

HESEB is the first soft X-ray beamline at SESAME and will significantly expand the research capabilities available to the user community in the Middle East and neighbouring regions. The source of the HESEB beamline is based on an elliptical polarising insertion device of the APPLE-type. The undulator's ability to provide linearly to circularly polarized light makes the beamline very suitable for materials science applications, especially magnetic materials. Its plane grating monochromator uses exchangeable gratings to cover a photon energy range from 70 eV to 2000 eV [1].

SESAME employs the Experimental Physics and Industrial Control System (EPICS) toolkit for controlling both machine and beamlines. EPICS is a control system middleware or framework for acquiring and controlling equipment through standardized communication between distributed components of different subsystems. The goal of beamline control system is to provide the users an easy interface to interact with the beamline components and devices. All beamline devices are connected to central units called EPICS Input Output Controllers (IOCs). These IOCs are hosted on Virtual Machines (VMs), there are three VMs per beamline, all of which reach the same network with the rest of the beamline's devices and hardware. A beamline network is separated from the other beamlines and machine networks. External access to beamline IOCs is provided through EPICS gateway.

CONTROL SYSTEM

Beamline control system consists of several sub-systems in which are illustrated in Fig. 1.

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Equipment Protection System (EPS)

Each beamline has its own independent EPS in order to keep the devices and components safe while they are operating. It constantly checks the status of the beamline's parts and collects signals from field sensors to allow or inhibit the operation of beamline. This includes:

- Temperature measurement to protect beamline components where high heat loads are expected.
- Monitoring of coolant flow rates and react in case of insufficiency.
- Control the vacuum valves based on the signals received from the vacuum gauges and ion pumps.
- Watch the shutters' opening and closing time and report it to the control system. Also, it reacts in case of fail to close or limit switch failure.

PLC The EPS of SESAME's beamlines are PLC based. SIEMENS S7-1500 is the main controller used in HESEB. This model replaced the older SIEMENS S7-300, which was used in all beamlines before HESEB. Recently, a decision was made to consider the S7-1500 and S7-1200 in all new projects as the S7-300 model will be discontinued in 2023 [2]. Building of HESEB PLC control racks including PLC wiring, wiring diagrams, PLC coding and system commissioning have been done completely in-house by the control team and trainees.

PLC Programming The process of PLC programming begins with requirements analysis. Next, a matrix of causes and effects is defined, and finally, the PLC code is created and tested using this matrix. The PLC code structure is based on main routine, sub-routines and functions. This structure helps standardize the PLC programs and minimize programming errors. Moreover, it is easy to commission and understand, and flexible to upgrades.

EPICS Driver To connect the S7-1500 PLCs with EPICS, we used s7-nodave device support which is based on Asynchronous EPICS driver (ASYN) and libnodave library to communicate with S7 PLCs. s7-nodave does not require any special programming on the PLC side. Instead, the EPICS records just specify the memory address in the PLC to read or write the data [4].

Vacuum System

The control of vacuum system in HESEB consists of gate valves, TPG366 and TPG500 gauge controllers, IPCMini ion-pump controllers from Agilent and VAT fast valve controller. Remote monitoring and control over these devices is essential during operation of HESEB. The control interface

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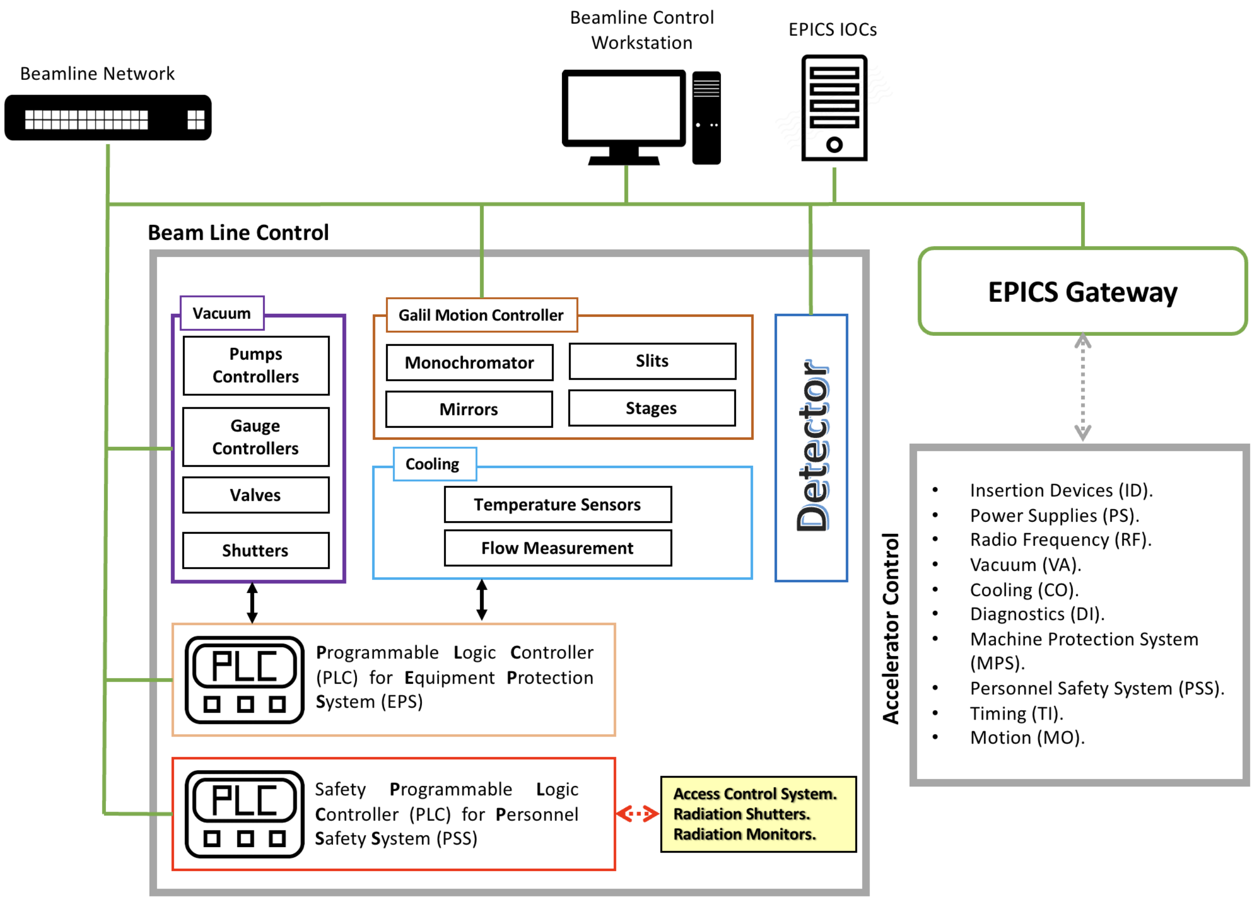

Figure 1: General layout of beamline control system.

can be divided into two categories; low level signal integration and smart controllers interface; low level signals are mainly the interlocks signals from gauges and pumps. These signals are transmitted to the PLC which will act accordingly to allow opening the valves or force them to close in case of emergency. Interlock levels can be configured either directly from the gauge/ion pump controller or from the control system Graphical User Interface (GUI). Gauge and ion-pump controllers are connected with vacuum IOC over Ethernet connections. A dedicated GUI shows the important parameters from gauge controllers; channel pressure, status, temperature, operating hours, in addition to read/write privilege over filter time, upper threshold, and lower threshold. Another dedicated GUI for ion pumps shows pressure level, current, voltage, maximum allowed power, pressure set-points, and current protection.

Motion System

SESAME uses Galil DMC as standard motion controllers. HESEB's motion system has four controllers that control the stepper motors of the beamline, namely for movable mask, slits, M1 mirror, Plane Grating Monochromator (PGM), M2 mirror, M3 mirror, M4 mirror, and sample manipulator. We use the standard ASYN based EPICS driver for Galil products, this driver is maintained and supported by the EPICS community. Mirrors and PGM coordinate motion were implemented using the EPICS standard transform record. The transform record supports multiple equations in a single record, however due to the complexities of the PGM coordinate motion we decided that each equation for motion would be implemented into one transform record. This allowed us to easily debug and trace the behaviour of the PGM's coordinate motion and prepare it for commissioning. Before moving the PGM motors, the EPICS motor simulation module (MotorSim) was used to test and validate the system.

Detectors

Three detectors are installed at HESEB, Bruker QM 100 and two Kiethly picoammeters. The QM100 is an X-Ray spectrum detector used for energy-dispersive X-Ray applications. For the control system, the device is supported by the Multi-channel Analyzer (MCA) EPICS module under Windows OS. On the other hand, ASYN driver was used to control and acquire current readouts from the Kiethly detectors.

Personnel Safety System (PSS)

As a soft x-ray beamline, HESEB does not require shielding hutches. Front end shutters and radiation monitors are connected to the main personnel safety system of the accelerator.

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HESEB CONTROL GUI

Beamline users interact with control systems through GUIs. SESAME beamlines, including HESEB, employ Qt as its GUI client. EPICS Qt is a Qt interface to EPICS' channel access protocol developed at the Australian Synchrotron [4]. The interface contains an API to read and write EPICS PVs across many widgets.

One of the main advantages of Qt is rich coding in GUI design; it allows implementing custom logic in the GUI. At SESAME, we run the Qt clients on a custom version of EPICS Qt where we customized some widgets like Indicators, labels and text boxes. This has been done by adding some channel access (CA) initialization and status update code. The main GUI in the beamline shows an overview of the beamline consisting of its three main sub-systems; front-end, optics and end-station as well as information from the machine through the EPICS gateway like beam current, energy, lifetime and ID gap. Block diagrams representing the beamline components are also displayed in the main GUI; the blocks are color-coded as follows:

- Red: component is interlocked
- Yellow: valve or shutter is closed.
- Green: component is in the operational state, or valve/shutter is open.

In addition, each block will show values for any connected thermocouples as well as pressure readouts for any gauges or ion-pumps. The buttons on the main GUI will show red color to indicate that this sub-system has an interlocked component.

PLANE GRATING MONOCHROMATOR

HESEB beamline consists of a collimated PGM attached to an elliptical undulator. The mechanics of the grating chamber comprises of two optical elements, a plane pre-mirror, and a plane grating in which they rotate around separate axes.

Control Aspects

PGM can be operated in one of three modes: fix deflection, fix diffraction, or fix magnification magnitude. The three modes of operation include set of equations, each mode has its own equations which must be enabled only when the relevant mode is selected. Equations of the other two modes must be disabled in order not to interfere with the running one. The complexity of the equations is hidden from users by an easy to use and interactive GUI. The design of PGM control software started by modeling the system graphically and building publisher-subscriber trees, Fig. 2 shows an example, then implementing the equations inside EPICS database using transform record, which provides the capability of solving set of equations sequentially. This technique provides an easy way to discuss the details of application with optics experts, it helps in software development, and it makes software testing easier.

Energy selection in PGM is done by selecting the proper angles: incident, deflection, and diffraction, the system also

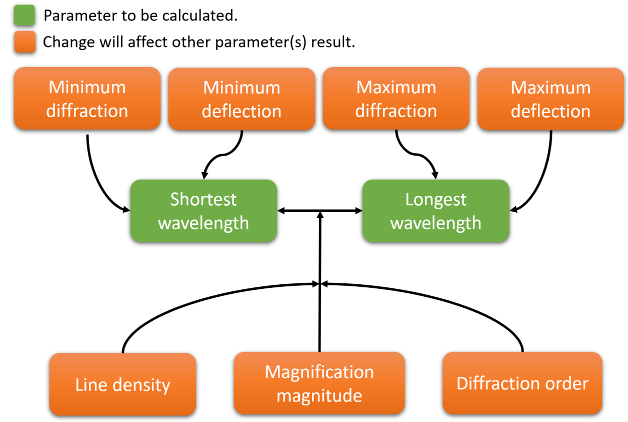

Figure 2: Publisher-subscriber tree for wavelength range calculation in fix magnification mode.

gives the user control over diffraction order, line density per meter, exit slit size and magnification magnitude – in fix magnification magnitude mode. Control system provides the user real-time information about energy resolution for the whole system and more details regarding each part (slit, pre-mirror, grating, etc.). Moreover, the system gives the user the ability to provide a range of deflection and diffraction angles and get the shortest and longest wavelengths.

PGM Safety

An important aspect in PGM control is safety. A set of safety layers to protect the mirror and the grating have been implemented. As a first layer of protection, control software calculates the target angles and triggers a stop command to the motors in case the calculated angle difference between them is below a certain threshold. Indicators in the GUI will turn red to notify the user to check the input parameters again.

Then the second layer of security comes in; if the angle difference touches the predefined threshold, in such scenario the motors are completely disabled by a hardware signal and it is mechanically latched, then the user cannot move the motors anymore until an expert personnel enables them again manually.

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