The control system for water-cooled DCMS in SSRF (Postprint)

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Abstract

A monochromator is important to a beamline for desired monochromatic light. There are three water-cooled double crystal monochromators (DCMs) commissioned in the phase-I beamlines of Shanghai Synchrotron Radiation Facility (SSRF). In this paper, the mechanical principle of the DCMs is introduced. A control system for the monochromator based on the standard architecture for SSRF beamlines is described. To achieve the control requirement precisely, the hardware includes VME (Versa Module Eurocard)-based controller for stepper motors, RS-232-based controllers for micropositioning and piezoelectric actuators. The software is developed with EPICS (Experimental Physics and Industrial Control System) package. Test results have revealed the stability and reliability of the system.

Full Text

Preamble

The Control System for Water-Cooled DCMs in SSRF

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A monochromator is essential for beamlines to produce desired monochromatic light. Three water-cooled double crystal monochromators (DCMs) have been commissioned in the phase-I beamlines of the Shanghai Synchrotron Radiation Facility (SSRF). This paper introduces the mechanical principle of these DCMs and describes a control system based on the standard architecture for SSRF beamlines. To achieve precise control, the hardware includes VME (Versa Module Eurocard)-based controllers for stepper motors and RS-232-based controllers for micropositioning and piezoelectric actuators. The software is developed using the EPICS (Experimental Physics and Industrial Control System) package. Test results demonstrate the stability and reliability of the system.

Keywords: EPICS, Water-cooled DCM, Motion Control, SSRF
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Introduction

Three water-cooled double crystal monochromators (DCMs) are installed on the XRD (X-ray Diffraction), SAXS (Small Angle X-ray Scattering), and HF (high flux) beamlines at the Shanghai Synchrotron Radiation Facility (SSRF) [1]. The control systems for the two DCMs built in 2008 were developed with LabVIEW by the manufacturer, which has created significant operational and maintenance challenges because their hardware and software differ substantially from the standard architecture of the overall beamline control system. For the newly constructed HF beamline, the DCM control system was developed using the standard EPICS platform [2] and has been operating properly since June 2013. The control system for the SAXS beamline was also upgraded to EPICS in 2013.

The working principle of the DCMs is similar across all beamlines. Each employs a pair of crystals in a dispersion-free arrangement where the first crystal diffracts the incident white synchrotron beam while the second crystal adjusts in multiple dimensions to maintain the exit beam fixed and parallel to the incident beam. According to Bragg's equation, the desired photon energy is determined by the Bragg angle, allowing different energies to be selected by controlling the Bragg angle B:

$$2d \sin \theta_B = n\lambda$$

where d is the lattice diffraction constant of the crystal and n is the diffraction order (normally $n = 1$).

The Bragg rotation axis is designed to pass through the center of the reflecting surface of the first crystal. Figure 1 [Figure 1: see original paper] illustrates the axis definition for the DCM [3]. During Bragg axis rotation, it is necessary to adjust the angles and displacements of both crystals to fix the exit beam height and direction.

While some motion mechanisms are similar across DCMs, each has distinct mechanical components. The second crystal of the XRD beamline includes a bender adjustment to focus the X-ray beam, whereas the second crystal of the HF beamline is equipped with a piezoelectric actuator for high-resolution adjustment. The physical variables and components of the three SSRF DCMs are listed in Table 1 .

TABLE 1 Physical variables and components

Phys. variables	Roll1	Roll2	Pitch2	Pitch2-Piezo	Bender
Components	P843.6	HSG-DVRT-6	*They use the same components as follows: B, VRDM 397/50; PK569-B PK566-B PK566-B PK569-B PK566-B PK566-B Z2, PK566-B; Temperature monitor, Pt100.*		

II. Hardware

The DCMs employ five control modes utilizing stepper motors and precision actuators to control the Bragg angle, T2, Z2, Roll1, Roll2, and Yaw2. DVRTs (Differential Variable Reluctance Transducers) serve as linear displacement sensors to monitor the position of micropositioning actuators, while a piezoelectric actuator fine-tunes the pitch of the second crystal. Additionally, the temperature inside the DCM chamber and the cooling water cycle unit require monitoring.

Following EPICS' distributed architecture, the hardware comprises three layers: an operator interface (OPI), an input/output controller (IOC), and motor drivers or position monitors. Figure 2 [Figure 2: see original paper] shows the SAXS DCM hardware architecture, which is largely similar to that of the HF

DCM, though the HF DCM uses DVRTs—the world's smallest linear displacement sensors—to measure angular displacement.

The OPI is an HP-PC running operator interfaces on a Linux operating system with EPICS high-level tools. Two IOCs are implemented: a VME (Versa Module Eurocard) system and an HP-PC. The VME system includes an MVME5500 processor and a MAXv-8000 motion controller. The MVME5500 is a PowerPC604 CPU running the VxWorks 5.5 real-time operating system. The MAXv-8000 is a VMEbus-based motion controller capable of managing up to 8 axes of open-loop stepper, closed-loop stepper, or servo systems, and it connects to 5-phase stepper motor drivers. The OPI communicates with the IOCs via Ethernet [4]. The soft IOC runs on the HP-PC, managing devices based on serial communication. The micropositioning actuators M230 and piezoelectric actuator P843.6 are controlled by three C-863 controllers and one E621 controller, respectively, all operating in serial mode. A serial server facilitates communication between the PC/IOC and serial port equipment, while an ADAM4015 module monitors temperature.

III. Software

A. Software Structure

EPICS is a collection of software tools and applications that provide infrastructure for building distributed control systems to operate devices. The latest EPICS version for Linux is used in this control system, employing four support modules: asyn, motor [5], calc [6], and StreamDevice [7], all available in the APS (Advanced Photon Source) synApps package [8].

Several methods exist for developing EPICS control applications: building runtime databases, programming function codes with SNL (State Notation Language), or writing application programs in Python. A runtime database or SNL program runs in an IOC, while Python programs run at the OPI level. Editing a runtime database by combining records is effective and user-friendly for applications. After editing with a simple text editor, the database is specified in a startup script file and loaded automatically into the IOC along with other libraries and configuration files when the IOC starts.

Record fields can be accessed by OPI clients through Channel Access (CA). Based on network protocol sockets, CA provides not only simple functions for client development but also specialized designs for high bandwidth through its client-server mode and callback mechanism.

B. Motion of Single Stepper Motor

The motor record is a fundamental component of the beamline motion control system, containing over 100 fields corresponding to stepper motor parameters such as resolution, run direction, and velocity. The essential motor control functions involve moving the motor to a set position at a predetermined speed and commanding the motor to stop when a limit is activated. Each field in the motor record must be configured correctly.

C. Energy Regulation and Linkage Control

During beamline operation, beam energy and position are of greater concern than the Bragg angle or individual motor values. Therefore, the control software must provide physical variables, which can be implemented by combining motor records, soft motor records, and transform records.

In the runtime database, real stepper motors are represented by motor records, while physical variables are represented by soft motor records. Transform records calculate values between physical variables and real motor parameters and coordinate operations between motors.

EPICS records have INP/OUT fields for getting/putting values from/to other records, enabling three main linking modes [9]: PP (process passive), NPP (not process passive), and CP (channel access and process). These linking modes allow programs to form loops that implement algorithms among motors. The DCM control database contains two such loops: one employs two transform records to convert between Bragg angle and energy, while another, shown in Figure 3 [Figure 3: see original paper], implements coordinated motion between Bragg and Z2. When the Bragg angle moves, Z2 must move according to the following equation to maintain a fixed exit beam position:

$$nZ = H/[2(1/\cos\theta - 1/\cos\theta_0)]$$

In this loop, a transform record calculates the Z2 displacement relative to the Bragg angle.

To meet different requirements during beamline commissioning, operation, and maintenance, two working modes are provided: coordinated motion and independent motion. In the GUI (Graphical User Interface), shown in Figure 5 [Figure 5: see original paper], pressing the YES button causes Z2 to always coordinate with the Bragg angle, while pressing the NO button allows the Bragg angle and Z2 motors to move independently. In independent mode, the Z2 offset can still be compensated by activating the Compensate button. The program workflow is illustrated in Figure 4 [Figure 4: see original paper].

D. Control for Serial Devices

The StreamDevice module is used for the ADAM4015 and the multichannel signal conditioner [10] that acquires DVRT signals. It provides generic device support for devices with a "byte stream" based message communication interface. For receiving and sending messages, it uses ai/ao records whose INP/OUT fields specify a protocol file followed by a special function. The record and protocol for ADAM4015 are as follows:

```
record(ai, "RollTemp")
    field(DESC, "4015 X16B1:T0")
    field(PREC,"2")
    field(DTYP, "stream")
    field(INP, "@temp.proto gettemp( YawTemp, YTemp, ZTemp, PT1, PT2) NP5610-temp")
    field(EGU, "A")
    field(SCAN, "2 second")

record(ai, "YawTemp")
    field(DESC, "4015 X16B1:T1")
    field(PREC,"2")
```

Filename: temp.proto

```
OutTerminator = CR;
InTerminator = CR;
f = 0x21;
gettemp
    out "#\x30\x31";
    in ">%f%($1.VAL)f% ($2.VAL)f% ($3.VAL)f%($4.VAL)f%($5.VAL)f";
```

"temp.proto" is the ADAM4015 protocol file defined in the startup script. The RollTemp record is a StreamDevice record whose INP field links to the 'gettemp' function in 'temp.proto', which assigns a series of values from ADAM4015 to the soft ai records YawTemp, YTemp, ZTemp, PT1, and PT2. YTemp, ZTemp, PT1, and PT2 are defined similarly to YawTemp in the database file.

E. Save and Restore Parameters

Beamline scientists invest considerable effort in adjusting motors to achieve optimal beamline performance. By default, when the system powers off, motor positions and other parameters are lost completely, requiring complete recommissioning from scratch when power is restored. Therefore, automatically saving key parameters during beamline operation is essential. The "autosave" module periodically saves EPICS record field values and restores them when an IOC restarts. Two text files, "positions.req" and "settings.req" [11], are required: "positions.req" specifies value fields while "settings.req" lists other parameter fields. Based on these files, the EPICS IOC updates field values to "positions.sav" and "settings.sav" files, which are automatically restored when the IOC restarts to recover the beamline's original state.

F. Graphical User Interface

The DCM control OPI interface is built with CSS (Control System Studio) [12], an Eclipse-based tool collection that integrates alarm handling, archive engine, operator interface, and diagnostic functions. In this application, CSS-BOY—the most notable CSS component—replaces EDM (Extensible Display Manager) for building interfaces via drag-and-drop functionality with instant data connection, greatly simplifying GUI creation. Figure 5 [Figure 5: see original paper] shows a screenshot of the control interface. All data can be easily archived by the RDB channel archiver and accessed quickly and directly by authorized users via web browser from any networked computer [13].

IV. Tests and Results

The Bragg angle at BL17B1 covers a range of 5.67°–23.29°, corresponding to an energy range of 5–20 keV with Si(111) reflection. During energy scanning, maintaining parallelism between the two crystals is crucial for stable beam intensity, which decisively influences user experiments. DCM performance can therefore be evaluated by measuring crystal parallelism, which was tested at the manufacturer. Figure 6 [Figure 6: see original paper] shows the test results (the insert displays the test platform), demonstrating that the parallelism of the two crystals is within 2 arcseconds, meeting the required specification.

After integrating the DCM control system into the HF beamline, tests were conducted to verify energy resolution. An ionization chamber downstream of the monochromator provided photon flux information. The DCM rocking curve is shown in Figure 7 [Figure 7: see original paper], with a FWHM of 0.00215°. The energy resolution exceeds the design specification of 3 ×10^{-4}.

V. Conclusion

The control system based on standard hardware and software architecture not only facilitates adoption of successful experience from similar devices but also provides significant benefits for operation and maintenance. The DCM control system has operated stably and reliably since September 2013 and will be applied to future beamlines.

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Note: Figure translations are in progress. See original paper for figures.