

Implementation of effective control system for variable-included angle plane-grating monochromator

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Abstract The variable-included angle plane-grating monochromator is a homemade key equipment of the scanning transmission X-ray microscopy (STXM) beamline at Shanghai Synchrotron Radiation Facility (SSRF). Monochromatic light of various wavelengths is achieved by an effective control system that handles the rotation of the plane mirror and plane grating mounted in a high vacuum chamber. M511.DDB made by PI Corp. is used as motion stage which has a DC servo motor controlled by a C862 controller based on RS232 protocol. The software platform of STXM is EPICS, so the local control functions are implemented by LabVIEW program to satisfy physics control. For the remote control functions, the program is integrated into EPICS with ShareMemoryIOC. Experimental tests show that the repeat precision of motion control is less than 0.2 μm , which meets the control demand.

Key words Synchrotron radiation, Monochromator, LabVIEW, EPICS, Beamline control

1 Introduction

Shanghai Synchrotron Radiation Facility (SSRF), a third-generation synchrotron radiation light source, has been opened to users since its commissioning in 2009. As one of the seven Phase-I beamlines, the scanning transmission X-ray microscopy (STXM) beamline is equipped with a variable-included angle plane-grating monochromator^[1,2]. This key equipment consists of a plane mirror and a plane-grating without incidence slit. The working energy can be chosen from 250 eV to 2 keV by changing the variable-included angle.

This kind of monochromator has been used in several advanced light sources, such as ALS and BESSY II^[3,4]. In China, Changchun Institute of Optics, Fine Mechanics and Physics (CIOMP), Chinese Academy of Sciences designed such a monochromator for Hefei Light Source about ten years ago. Its motion control is achieved by a step motor that moves the target to its position rapidly. However, the position error cannot be adjusted automatically when the motor

loses steps due to the lack of a closed-loop control system.

An updating design was carried out by CIOMP and SSRF. Two stages were adopted to control the mirror motion and the grating motion for mounting DC-Servo motors^[5] from Physik Instrumente (PI) GmbH. The PID closed-loop control for servo motor provides longer time of stable status than using a step motor, but the position precision is 0.1 μm .

Experimental Physics and Industrial Control System (EPICS)^[6] is a distributed network control system widely used in large scientific facilities in the world. At SSRF, the control system for all beamlines is based on EPICS for standardization. Motor control technology for 2-phase or 5-phase step motor under the EPICS platform was developed and implemented for several beamlines at SSRF. This standard control method cannot be used for DC-Servo motor due to different interface protocols. Adhering to the basic rule that all of the beamline optics devices must work under EPICS, it is necessary to find out a solution.

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As a well-known software for control and measurement, LabVIEW^[7] is a powerful tool to design local control program for the monochromator. As an interface tool, ShareMemoryIOC^[8,9] can be applied for data interchanging between LabVIEW and EPICS. Thus the EPICS control of the monochromator can be realized with ShareMemoryIOC.

2 Hardware design

Both the plane mirror and plane grating have a sin-bar scanner. According to the mechanical design, two linear drivers are used for controlling the sin-bar scanners. M511.DDB motion stage is chosen as the linear driver with maximum motion range of 0–102 mm. It has a positive limit switch, a negative limit switch, a home switch and an encoder. The resolution of encoder is 0.1 μm . Especially, a brake is also mounted to hold the stage position in case of power supply failure or other errors. As the DC-Servo motor controller, C862 receives the commands from a PC based on RS232 protocol and handles the motor motion. The C862 is over 25 m from the PC. So Moxa RS232/485 converter and Moxa PCI RS485 cards are adopted to avoid the signal attenuation. The hardware system (Fig.1) is made of commercial products, featured by the simple framework, low failure rate and convenient maintenance.

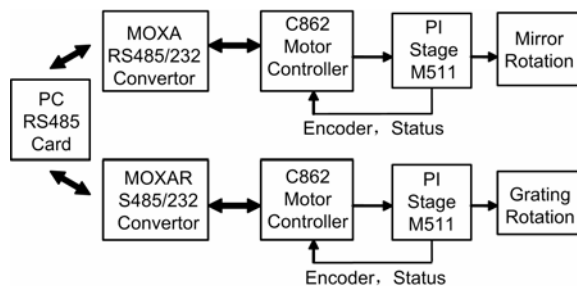


Fig.1 Wiring diagram of hardware.

3 Software design

The hardware design includes the motion control, the safe control, the data exchange between LabVIEW and EPICS, the operation interface and the test.

3.1 Motion control of mirror and grating

The grating incidence angle α , diffraction angle β and the mirror incidence angle φ are shown in Fig.2.

The angles of φ and β can be calculated by Eqs.(1) and (2).

$$\varphi = \arcsin[(h_p - h_{p0})\mu/L_p] - Z_p \quad (1)$$

$$\pi/2 - \beta = \arcsin[(h_G - h_{G0})\mu/L_G] - Z_G \quad (2)$$

where h_p and h_G are the encoder readout counts of the mirror and the grating, respectively, h_{p0} and h_{G0} are the encoder counts when the sin-bar scanners locate the reference position, μ (mm) is the resolution of encoder, L_p and L_G (mm) are the length of the sin-bar scanners, Z_p and Z_G (rad) are the variable-included angle between the surface and horizontal plane when the sin-bar scanners locate the reference position.

The energy of monochromator can be calculated Eqs.(3)–(5).

$$m\lambda = (d + \Delta d)(\sin\alpha - \sin\beta) \quad (3)$$

$$\lambda = hc/E \quad (4)$$

$$\alpha = \pi - 2\varphi - \beta \quad (5)$$

where λ is wavelength, E is energy, m is the diffraction order, d is the space of grating ruling, Δd is the corrected value of the space, h is Planck constant, and c is the velocity of light in vacuum. The chamber is mounted with two gratings, which can be switched by manual operation. When No.1 grating is chosen, $m = -1$ and $d = 1.25 \times 10^{-3}$ mm, while $m = 1$ and $d = 8.3336 \times 10^{-4}$ mm when No.2 grating is chosen.

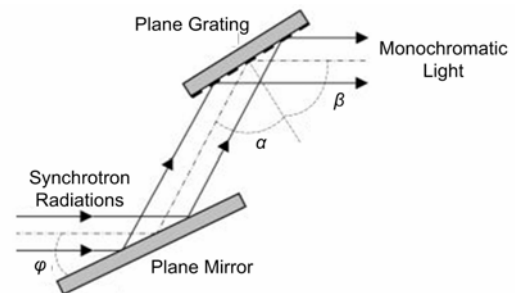


Fig.2 Sketch of the optics.

The necessary parameters described above were measured and given in Table 1.

Table 1 Parameters of measurement

Parameters	Values	Parameters	Values
L_p / mm	693.22	h_{G0}	451813
h_{p0}	393273	Z_G / rad	-0.36627
Z_p / rad	-0.96270	Δd	0
L_G / mm	694.71		

In reverse, when moving the mirror or the grating to a new angle, the new target position of encoder can be calculated according to Eqs.(1) and (2). Sending the new target value to C862 controller through serial port, motion of the mirror or the grating will be handled by the controller.

3.2 Safe control of equipment

Because of the special structure and working principle, a collision would occur between sin-bar scanners of the mirror and grating if the control program had a mistake. Another risk is if the beam reached a wrong place, some parts would be damaged by over heating. Then, the control program must be reliable, and the rotation condition judgment and the logic control of brake must be realized, so as to keep the system from the risks.

Three conditions must be satisfied. First, the beam must reach the mirror surface. Next, the beam cannot touch side face of the grating. Finally, the two sin-bar scanners cannot collide during their movement. Each condition has a series of formulas, with which LabVIEW subVIs are developed to judge whether the conditions are meet or not.

The stage can hold the current position by motor servo mode or brake. If the motor brake did not lock after the servo function disables, the sin-bar scanners would slip down and collide together. So it is important that the brake and the servo mode meet the logic interlock as follows: (1) to unlock the brake only when the servo mode is active; (2) to disable the servo mode only when the brake is active; and (3) to lock the brake immediately when the stage reaches the positive or negative limit. The brake is on the lock status when it is powered on. Enable the servo mode, unlock the brake, and send the new target position to C862, are the right actions for starting work.

3.3 Data interface between LabVIEW and EPICS

As a data interface tool, ShareMemoryIOC is installed on a PC running Windows operating system. There are many subVI functions in the SM.lib file, which are used to interchange all kinds of data between LabVIEW and EPICS. At the directory called ShareMemoryIOC, all necessary files for running a soft-IOC server are exist there. Function SM

StartIOC.vi can start run the soft-IOC server and it must be called at the initialization of program. The EPICS database file is to be edited for the soft-IOC server. The EPICS records, called as progress values, are putted into the database file. These records must correspond with LabVIEW variables one by one.

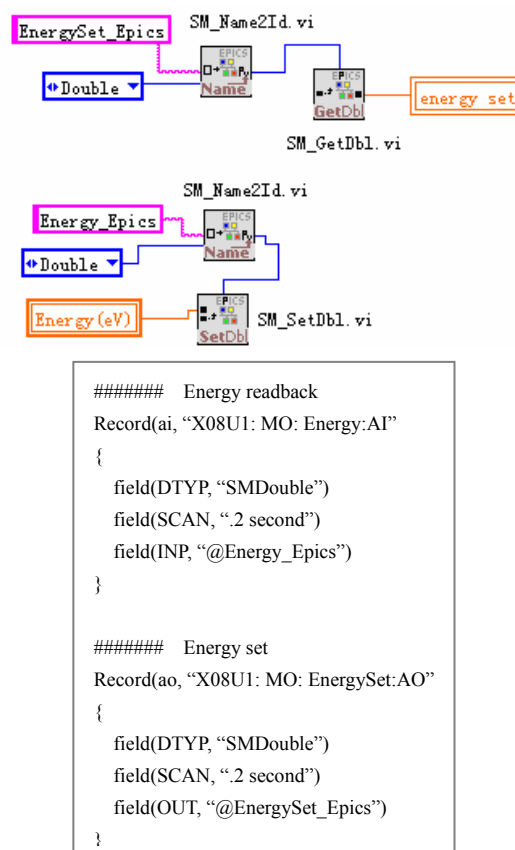


Fig.3 Data interface between LabVIEW and EPICS.

Taking the energy set and readback as an example (Fig.3), the string “EnergySet_Epics” links the LabVIEW variable “energy set” to the EPICS record “X08U1:MO:EnergySet:AO” by using the SM_Name2ID.vi function, and transfers the value of “X08U1:MO:EnergySet:AO” to “energy set”, by using the SM_GetDb1.vi function. Similarly the string “Energy_Epics” links the variable “Energy (eV)” to the record “X08U1:MO:Energy:AI” by using the SM_Name2ID.vi function, and transfers the value of “Energy(eV)” to “X08U1:MO:Energy:AI” by using the SM_SetDb1.vi function. Through these link operations, free interchange of the data between LabVIEW and EPICS is realized. Another PC which runs Linux operating system with EPICS base and extended package, a monochromator’s remote control client is made to communicate with the soft-IOC

server based on the EPICS Channel Access (CA) protocol.

3.4 Operation interface and test

The LabVIEW local control panel was divided into four parts. Fig.4 is part of the plane mirror control. The others include the control area of the plane grating, energy and parameters. The monochromator EPICS control panel is designed with EDM extended tool, but layout of the panel is similar to the arrangement of LabVIEW operation interface.

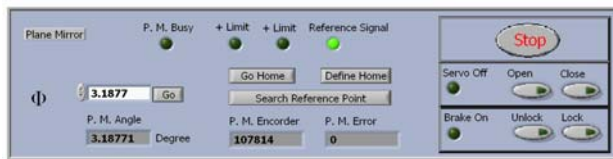


Fig.4 Control panel of plane mirror.

The motion test was carried out by using the encoder of stage. Table 2 shows the 10 test results of moving the plane mirror to 3.77° from other angles. The plane mirror positioning is perfect when the encoder readout is 37164. Due to working mode of the motor servo, adjusting the positioning error to zero is always needed. But the error here was recorded at the motor busy signal reset, indicating that the motion-repeated precision is better than $0.2 \mu\text{m}$. This meets the control demand well.

Table 2 Test results of the plane mirror positioning precision.

Readouts	Error / μm	Readouts	Error / μm
37163	-0.1	37165	+0.1
37164	0	37165	+0.1
37163	-0.1	37164	0
37167	+0.2	37164	0
37164	0	37163	-0.1

At the speed of $400 \mu\text{m/s}$ and PID of $P=120$, $I=40$, $D=200$, let the plane mirror motor move from the encoder count=1 to the encoder count=7. The test result of dynamic step response is showed in Fig.5. The x -axis is real time (s) and the y -axis is encoder readout count. Ten seconds (from the 9th to 19th second) were spent to adjust and stop stably, but the overshoot time (from the 11th to 19th second) is not worthy, because the overshoot of 2 encoder counts brings just about $0.2 \mu\text{m}$ errors. This corresponds to a $0.2\text{-}\mu\text{m}$

error of only 0.0028 eV in energy, which means nothing to a monochromator in practice. However for reducing the overshoot time, it is worthwhile to optimize the PID parameters.

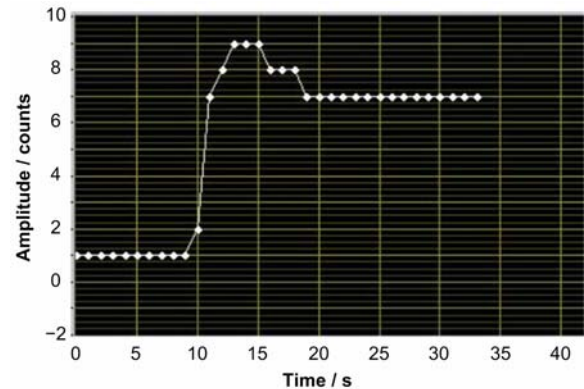


Fig.5 Test of dynamic step response.

4 Conclusion

Since Dec. 27, 2008 when the first monochromatic light was obtained at SSRF, the monochromator control system has been working well, without any hardware failure, program bug and communication jamming. The program realizes the angular individual control of the plane mirror and grating, and the energy linkage control. Its design specifications have been achieved.

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