ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPG22

IMPLEMENTATION OF EPU56 CONTROL SYSTEM AT THE TAIWAN PHOTON SOURCE

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Abstract

The elliptically polarized undulator with a period length of 56 mm, called EPU56, is part of the Taiwan Photon Source (TPS) phase-III beamline project. Its control system is built within the EPICS framework using motion controllers and EtherCAT. The control systems of EPU56 include a safety interlock system, which automatically stops movement based on limit switches, torque limit switches, emergency stop button, and readings from the enclosed linear optical encoder. In addition, the control system offers settings for adjusting the correction magnets' power supply and employs optical absolute encoder motors to control the movement of the Gap and Phase. In order to maintain stability during movement, PID control is applied to the motion process by the motion controller. To further enhance precision, the system also employs an integrator limit within the motion controller for additional adjustments. This paper describes the development of the control system and the improvement made to the insertion device movement process.

INTRODUCTION

The third phase project of the Taiwan Photon Source (TPS) beamline includes the elliptically polarized undulator (EPU) [1], specifically the EPU56, which is shown in Figure 1 and is currently in testing. The EPU56 insertion device, which uses permanent magnet technology, needs six motors in total for adjusting the gap and phase positions.

The Experimental Physics and Industrial Control System (EPICS) [2] and Ethernet for Control Automation Technology (EtherCAT) [3] serve as the foundation for control automation in the control system of the EPU56, ensuring system consistency and facilitating maintenance.

Figure 1: EPU56 of TPS Phase-III beamline project.

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Gap and Phase control, as well as the creation of hardware and software protection mechanisms and a Graphical User Interface (GUI) for user operation, are all included in the motion control testing of EPU56. During operation, high magnetic force from permanent magnets affects both the movement of Phase and Gap, which are controlled by EPU56 through motors. Hence, closed-loop control using linear encoders is used for the motor control of the EPU56.

DRIVER SYSTEM

With the motor driver set to torque control mode, EPU56 uses two servo motors to control the position of Gap. The drive configuration for Gap is displayed in Figure 2. The motor rotates a ball screw after going worm reducers and gear box. The ball screw has a 16mm gap width, and the worm reducer has a reduction ratio of 1:40 and the gear box of 1:25. As a result, after the motor passes through the reducers, its overall reduction ratio is 1:1000. The upper mounting bracket travels in tandem with the motor's complete rotation, causing a 32µm gap to open or close. The EPU56's gap can be adjusted between 17 and 120 mm.

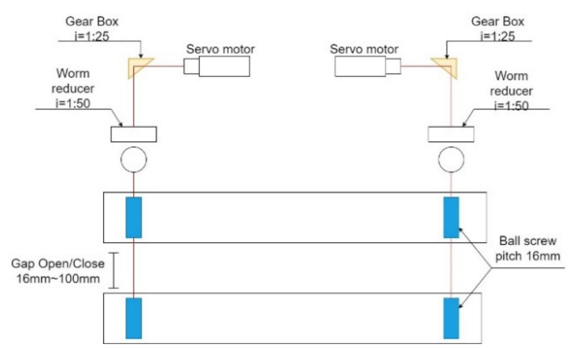

Figure 2: Gap driver mechanism of EPU56.

EPU56 uses four servo motors to control the position of Phase. The drive configuration for Phase is displayed in Figure 3. The motor rotates a ball screw after going gear box. The ball screw has a 16mm gap width, and the gear box has a reduction ratio of 1:100. As a result, after the motor passes through the reducers, its overall reduction ratio is 1:100. Phase moves 160µm after each motor completes a full rotation. Phase in the EPU56 has an adjustable range of -28mm to +28mm.

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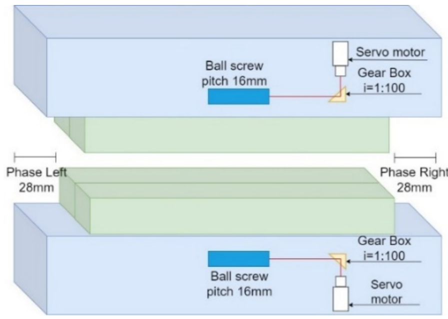

Figure 3: Phase driver mechanism of EPU56.

DESIGN OF EPU56 CONTROL SYSTME

Control System Architecture

A user interface, motion controller, motors and motor drivers, fast synchronous interface (BiSS C) optical encoders, limit switches, auxiliary position sensors, interlock safety, and emergency buttons make up the components of the EPU56 control system architecture [4], which is shown in Figure 4. EtherCAT and EPICS IOC technologies serve as the foundation for the control system [5].

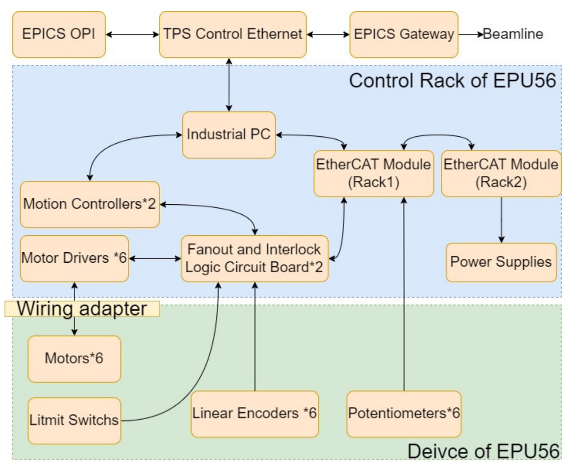

Figure 4: Control System Architecture of EPU56.

Industrial Computers based on Linux

Based on the Linux operating system, the industrial computer runs CentOS 7 and has three Ethernet ports assigned to the EtherCAT, TPS control system, and motion controller networks, in that order. Through the control system network, remote control is made possible by the industrial computer running EPICS IOC. Since Ethernet-based devices have become widely used, maintenance and upcoming equipment upgrades or replacements will be easier.

EtherCAT

A real-time Ethernet communication protocol called EtherCAT was created especially for automation control settings. To satisfy the real-time communication requirements of automation technology hardware and software, Beckhoff Automation first proposed it, and it was later published in the IEC standard IEC61158. EtherCAT's primary advantage is its low oscillation characteristics, which allow for more accurate synchronization, and its large cycle time reduction to less than 100 milliseconds. All slave nodes in an EtherCAT network get signals from the master controller, which are swiftly read by all slave devices, which then insert data into the frame as it travels downstream.

EtherCAT modules serve as the foundation for multiple functions of the EPU control system. These include potentiometer modules for reading potentiometer values, digital-to-analog converter (DAC) modules for reading power control outputs and motor drive status values, analog-to-digital converter (ADC) modules for controlling power output settings, and digital output modules for controlling 24V, 9V and 5V power switches and resetting torque limit switches. Correcting the magnet control section involves restarting the magnet controller, adjusting the output settings of the magnet power supply, and correcting the output readings of the magnet power supply.

An open-source EtherCAT communication solution for Linux platforms is the IgH EtherCAT master [6], which is now in use. Based on this master, Diamond Light Source (DLS) has created matching scanning programs that can transfer data over UNIX connections between the EtherCAT master and the EPICS IOC. For the purposes of this application, the data transfer between the PC (master) and the Ethernet module (slave) is set up to last for 2 milliseconds. The system requires an EPICS environment with asynDriver (asynchronous driver support) and Sequencer (snc/seq) modules in order to run EPICS IOC.

Motion Control

Motion controllers from the Galil DMC40x0 series [7] are used to solve difficult motion control issues like point-to-point positioning and jogging. They have two Ethernet connections thus one can daisy-chain numerous controllers and Computers with them. Two DMC-4040 motion controllers are used in the EPU56 system. They have four motion control axes and Biss C encoder feedback functionality, which are utilized to interface with motor drivers and optical encoders to create closed-loop control, which controls motor motion on both Gap and Phase.

Protection

Through the use of EtherCAT technology, motion controllers, interlocking protection circuit boards, and emergency stop buttons, we have implemented three layers of basic safety protection. In this system, we utilize circuit boards to distribute the outputs of limit switches and emergency stop buttons to the motion controller, EtherCAT module, and interlocking protection circuit board, creating three independent safety layers.

The first layer of protection is implemented by the motion controller, which is responsible for monitoring the travel limit switches and ensuring that the closed-loop position error remains within acceptable limits. The second layer of protection is implemented through software programs, which check the gap deviation every 10 milliseconds. If the deviation exceeds the preset limit, the system immediately shuts down the output of the motor drive. The third layer of protection is provided by the interlocking protection circuit board, which is dedicated to interlocking

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safety protection. When the system detects any abnormal signals, the interlocking protection circuit board immediately cuts off the output of the motor drive, swiftly stopping the motor operation. After resolving all errors, the system needs to undergo a reset procedure to resume operation.

Integrator Limit

PID is a widely utilized feedback parameter in industrial control systems. The system is more precise and reliable because of its adjustable proportional, integral, and derivative units. We use IL commands from the Galil DMC40x0 series motion controllers during movement and PID assistance for localization to guarantee the correctness of the platform movement. Integrator gain can be limited by IL commands, which maintain voltage control within certain limits. Our goal with this feature is to improve performance stability when moving and arriving at specific position. IL can be turned on or off using our usage approach, which is shown in Figure 5. When enabled, the movement speed is fixed at the maximum value if there is no movement or if it exceeds the maximum value; while movement, the position error and movement status are used to update the IL parameters.

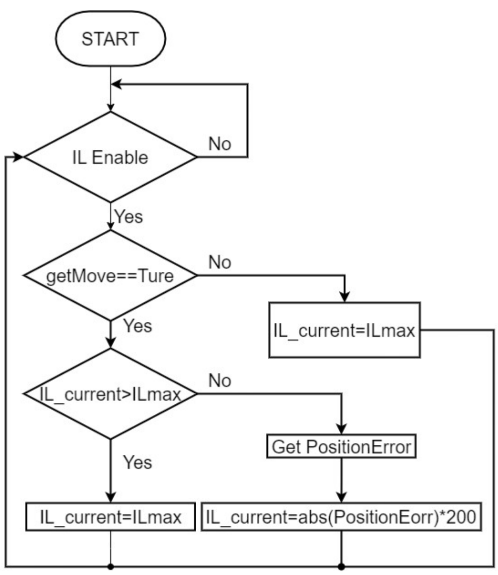

Figure 5: Motion control test platform moving.

Graph User Interface

Figure 6 displays the EPU56 motion control testing platform's simple graphical user interface. Users have the option to modify the Phase or Gap axis at the top of the GUI. They can enter certain places or adjust the position settings by using the buttons below. They may also use the button condition to control the motor's start, stop, and movement. The icons below will turn red when the limit switch is activated, and the motor will stop working right away. The platform's position at present is shown in the chart at the button.

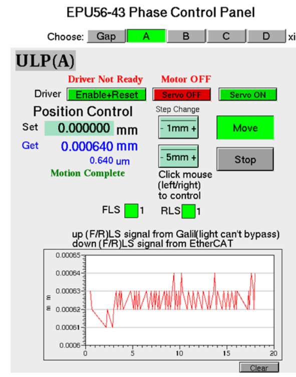

Figure 6: EPU56 Simple Graphical User Interface

MOTION CONTROL TEST

EPU56 and control system will be integrated in the fourth quarter of 2024. At the moment, we are testing the EPU56 control system on a motion control test platform. The motion control test platform's test results, which show a movement from 0 to 5 mm, are displayed in Figure 7. The motion testing platform position is shown in Figure 7(a), and its error during platform movement is shown in Figure 7(b). We used positional parameters like PID and IL. More precise positions are easy to obtain on the test platform with the help of IL. After the insertion device and control system are integrated, further confirmation of the stability during movement is still necessary.

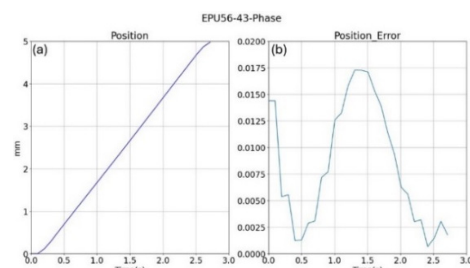

Figure 7: (a)Moving Position and (b) Position error

SUMMARY

This paper describes the content and development progress of the EPU56 motion control system, including the drive system of insertion device, the design of the control system, and the protection mechanism. The control system is developed based on EPICS and EtherCAT, currently in the testing phase of the motion control test platform, and integration with insertion device is scheduled for the fourth quarter of 2024. The system provides a graph user interface, allowing users to easily operate motor start-up and motor driver reset. A three-layer protection mechanism is implemented through motion controllers, limit switches, and interlock protection circuit boards. PID control combined with IL achieves more precise and easier position control.

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