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Control System for a Cryogenic Permanent Magnet Undulator at the Taiwan Photon Source

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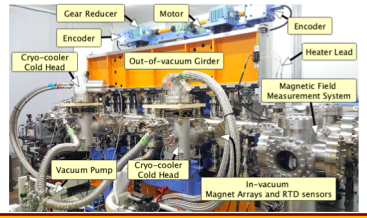
Abstract

Abstract—A hybrid cryogenic permanent-magnet undulator (CPMU) with a 15 mm period length is being constructed for a TPS Phase-II beamline. A control system for this CPMU (CU15) is under development since 2018 and is based on the Experimental Physics and Industrial Control System (EPICS) architecture and Ethernet Control Automation Technology (EtherCAT) framework. The main control components include a motor with encoder for gap adjustment, corrector magnet power supplies, ion pumps and BA gauges for the vacuum system, resistance temperature detectors (RTD) and heaters for temperature control of the cryogenic environment and magnet arrays, motion safety interlock, cryogenic system and vibration monitor system. The design and implementation of the CU15 control system will be summarized in this paper.

Introduction

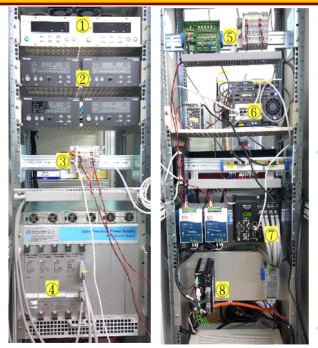
- A hybrid-type cryogenic permanent-magnet undulator (CPMU) with a 15-mm period length (CU15) is being constructed for the TPS Phase-II
- The design and implementation of the CU15 hardware, software, and temperature control system will be discussed in in this paper.



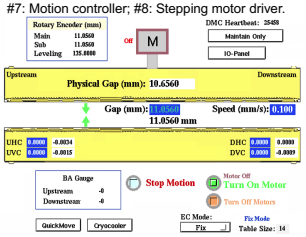
CU15 UNDULATOR SPECIFICATIONS FOR THE TPS

Items	Cryogenic Temperature	Room Temperature
Magnet material	$Pr_2Fe_{14}B$ (NMX-68CU)	
Period / mm	15	
Min. magnetic gap / mm	4.00	
Effective magnetic field / Tesla	1.30	1.13
Deflection parameter	1.81	1.58
Magnetic force / kN	31.8	23.0
Number of periods	133	
Total cooler capacity / Watt	400	
Operating temperature / K	80	300

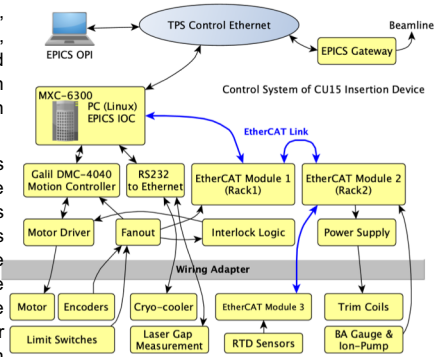
Control Environment



Control racks for the CU15.
#1: Ion Pump; #2: BA Gauge;
#3: EtherCAT I/O; #4: Corrector Power Supplies;
#5: Interlock circuit and EtherCAT I/O;
#6: MXC EPICS IOC;
#7: Motion controller; #8: Stepping motor driver.

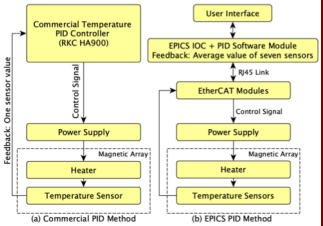


- The control system for the CU15 ID is based on the EPICS IOC and EtherCAT framework.
- The CU15 includes one stepping motor for gap control. The status of the axis is updated from the motion controller via private Ethernet using an UDP protocol and its update rate can be configured for 5 ms.
- The digital and analogue I/O for correction power supply control, reading of gauge pressures, temperature control and monitoring as well as vibration monitoring are based on EtherCAT technology.
- The interlock logic includes hardware and software components that monitors interlock signals and takes appropriate action. Three protection levels were implemented, including the hardwired logic, motion controller and software logic for motion protection.
- For the temperature protection, when the temperature of the magnet arrays is higher than the working temperature (80K), the mechanism will be deformed due to thermal expansion, so motion control cannot be performed to avoid mechanism damage.

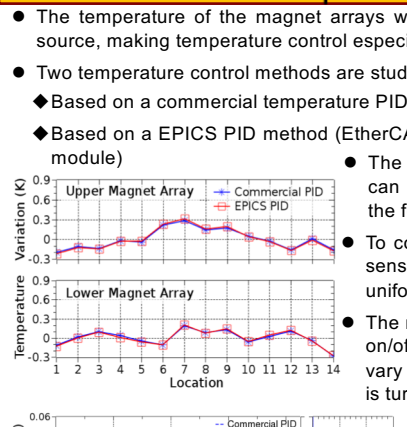


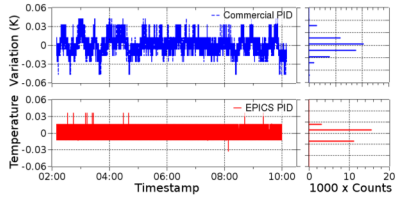
Temperature Control of Magnet Arrays

- The temperature of the magnet arrays will directly affect the quality of the light source, making temperature control especially important.
- Two temperature control methods are studied,
  - ◆Based on a commercial temperature PID controller (RKC HA900)
  - ◆Based on a EPICS PID method (EtherCAT I/O module plus EPICS PID software module)

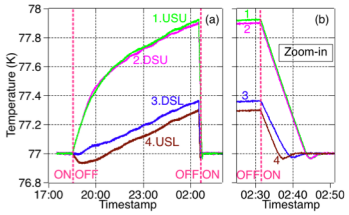


- The commercial PID temperature controller can accept only one RTD sensor signal for the feedback.
- To compare with the EPICS PID method, the average value of all seven RTD sensors is used as the feedback temperature input signal to obtain more uniformity and long-term stability of the temperature control.
- The magnet array temperature variation while the temperature feedback loop is on/off using the EPICS PID method. The temperature of the magnet arrays can vary by some 0.8 K within 8 hours and continue to diverge when the feedback is turned off. It takes around 15 min to stabilize when the feedback is turn on.

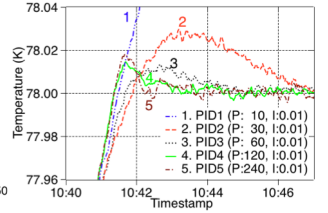




- Long-term temperature variation (left) and its distribution histogram (right).
- Commercial PID temperature controllers are used in the upper graph while the EPICS PID method is used in the lower graph.

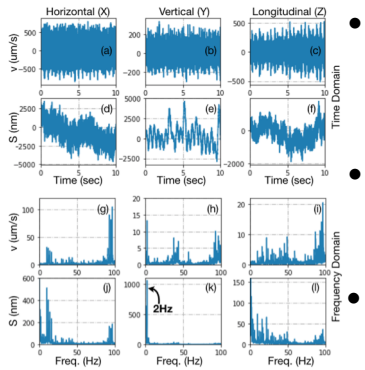


- (a) Magnet array temperature variation while the feedback loop is turned on/off.
- (b) Zoom-in of the feedback turn-on region.

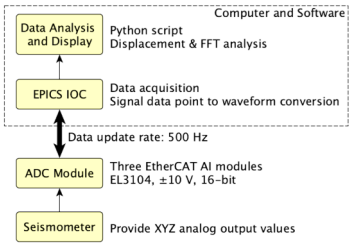


- Response comparison for various PID parameters of the EPICS PID method.
- The fourth PID parameter (P: 120, I: 0.01) is selected.

Vibration Issue



- A vibration monitoring system was developed using a seismometer and an EtherCAT analog module together with a python-based analysis program to calculate displacements and frequency domain spectra.
- Which allows are 500 Hz sampling rate of the EtherCAT modules for data capture. The horizontal and vertical vibrations while the cryo-coolers are set to 120 RPM operation.



- (k) shows that the intense 2 Hz motion is caused by the 120 RPM cryo-cooler operation. The effect of this vibration intensity on the electron beam stability will require further study after installation into the storage ring.

The graphs (a) to (f) show time domain data and (g) to (l) frequency domain data. The graphs (a) to (c) and (g) to (i) show the vibration velocity graphs (d) to (f) and (j) to (l) the vibration displacements. The graphs (a), (d), (g), (j) display horizontal plane vibration; (b), (e), (h), (k) vertical plane vibration and(c), (f), (i), (l) longitudinal plane vibration.

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