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RELIABILITY IMPROVEMENT FOR THE INSERTION DEVICE CONTROL IN THE TPS

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Abstract

Insertion devices (ID) are essential components in third-generation synchrotron light sources, which can produce highly-brilliant, collimated and quasi-monochromatic radiation over a broad energy range for experiments. Reliable operation of the insertion devices is important to users of beamlines. The most unpredictable fault is due to a soft error in optical absolute encoders due to radiation. There are several solutions to avoid such faults, e.g. by increasing the distance of the encoder from the beam, by a lead shield cover and finally by adopting an auxiliary position sensing device to help recovery from a fault. Efforts to improve operational reliability of the TPS ID controls will be discussed.

INTRODUCTION

The TPS includes one EPU46, two EPU48s and seven IUs (In-Vacuum Undulator) which are installed in seven straight sections to meet experimental requirements in phase I beamlines of the TPS project [1-4]. The ID control system was developed including gap/phase motion, protection system (hardware and software) and GUI development. All control systems for insertion devices are done by the NSRRC control team for economic reasons and delivery of a similar ID control environment is the goal.

The EPU48 includes six axes servo motors. Two servo motors control the gap, one on the upper girder and one on the lower girder. The other four servo motors control the phase, two on the upper and two on the lower girder. Each axis servo motor is connected to a rotary absolute encoder. In addition, each servo axis is tracked with a TR absolute linear encoder with 0.1 µm resolution, providing direct gap sensing and frame reference to eliminate effects of backlash. The EPICS IOC performs a software tilt calculation based on the linear encoder feedback in addition to the tilt sensors. With gap / phase change, the corrector magnets for IDs require very sensitive power supply controls to maintain very stringent beam stability requirements.

Our control plan for the phase-I insertion devices is based on the standard TPS cPCI EPICS IOC. The motion controller is based upon the Galil DMC-40x0 series Ethernet based motion controllers [5]. The controller is a full-featured motion controller packaged with multi-axis drives in a compact, metal enclosure. It controls the motors based on commands via Ethernet and receives commands from the EPICS IOC to handle motor motion and to read encoder positions, limit switches, position error and other states for monitor and software protection.

The motion controller is suitable for servo motors (EPU46, EPU48) and stepper motors (IU22). Closed loop gap adjustment is needed for varying phases of the EPU48 and EPU46. It can be copied with changing forces between upper and lower magnetic arrays. All motion axes include a synchronous serial interface (SSI), where the optical encoder connects to the motion controller directly. Each motion axis is accompanied with limit switches for over-travel protection. Synchronization of gap motion axes is essential to prevent tilt of the beam.

The hardware configuration for the TPS ID control is shown in Fig. 1 including cPCI EPICS IOC, 128 bits DI/DO module, ADC/DAC IP (Industry Pack) modules, motion controller, temperature monitoring solution and RS232/422/485 based devices of the insertion frame. High precision power supplies are used to control corrector magnets from feed forward look-up tables. Current designs include also the control interface for the beamline, e.g. the IU22 controls include an ion pump and ion gauge interface.

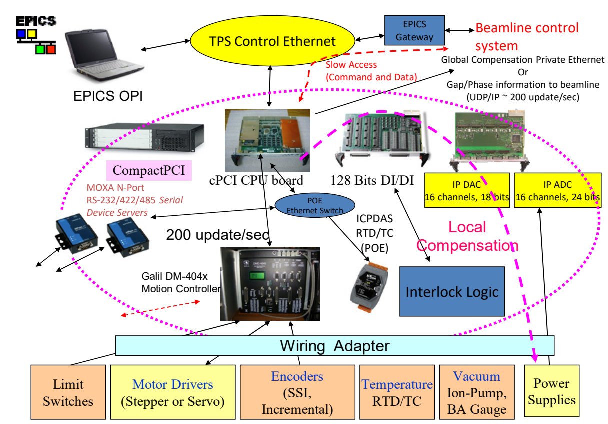

Figure 1: Basic hardware configuration for TPS insertion devices in Phase-I.

RADIATION EFFECT ON OPTICAL ABSOLUTE ENCODERS

Particle accelerators produce high energy protons and electrons, and the secondary particles produced by their interactions produce significant radiation damage on most semiconductor electronics components.

A single event effect (SEE) may be an electrical disturbance that disrupts the normal operation of a circuit. It is caused by the passage of a single ion through or near a sensitive node in a circuit. Single event effects can be either destructive or non- destructive.

Single-event upsets (SEU) or transient radiation effects in electronics are state changes of memory or register bits caused by a single ion interacting with the chip. They do not cause lasting damage to the device, but may cause lasting problems to a system which cannot recover from

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such an error. The error in device output or operation caused as a result of the SEU is called a soft error.

In very sensitive devices, a single ion can cause a multiple-bit upset (MBU) in several adjacent memory cells. SEUs can become Single-event functional interrupts (SEFI) when they upset control circuits, such as state machines, placing the device into an undefined state, a test mode, or a halt, which would then need a reset or a power cycle to recover.

TPS ID operation faces problems with absolute optical encoders fitted to the EPU48 and EPU46. The position of the encoders is close to beam level. The SSI encoders easily suffer soft errors by radiation when a beam dump or beam trip occurs. The encoders fail during a beam dump or beam trip as a result of a shower of particles disrupting the internal electronics.

There are three soft errors for SSI encoders: (1) the encoder generates erroneous position data and then auto recovers as shown in Fig. 2; (2) the encoder generates a wide range of position data that keeps jumping; (3) the encoder always sends a same serial data stream as shown in Fig. 3. Case (2) and (3) require a power cycle to recover.

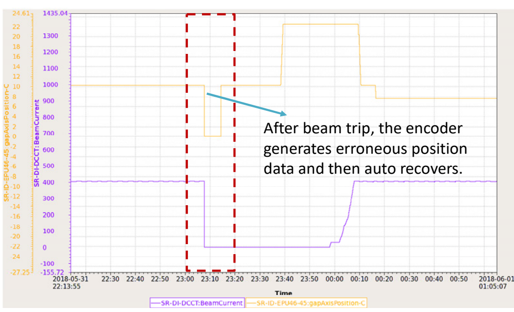

Figure 2: Case (1): the encoder of the EPU46 generates erroneous position data and then recovers.

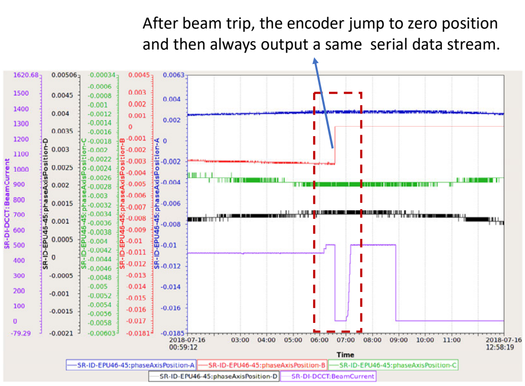

Figure 3: Case (3), the encoder stops sending a serial data stream.

Several safety protections are performed by the motion controller, which are over-travel limit switches, torque limits, stall, and close-loop position error limits. A limit threshold check of the encoder read-back is done by the EPICS IOC db-scan. According to encoder values, upper or lower beam tilt limits may also be monitored by the EPICS IOC. The encoder value is used to servo control and as input to many protection tasks. When the encoder stops sending an authentic serial data stream, the motion control will suffer unpredictable faults and motion control functions are invalid. In serious cases, it could lead to damage of the mechanical structure of the ID.

To avoid encoder damage and failure due to radiation, some 10 mm thick lead boxes are added around the SSI encoders of the EPU48 and EPU46 as shown in Fig. 4. Encoder soft errors are still occurring but the failure rate of encoders is reduced.

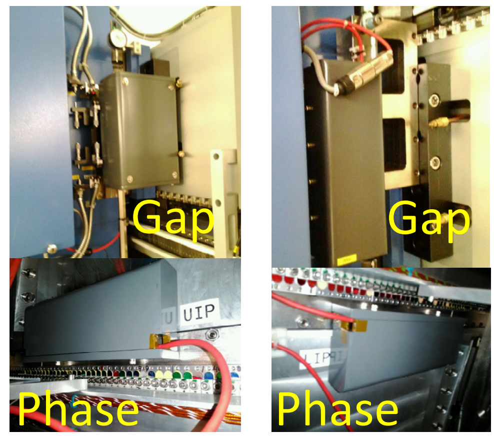

Figure 4: Lead boxes of more than 10 mm thickness are added around the SSI encoders of the EPU48 and EPU46.

DETECTION OF ENCODER ERRORS

The method of detection encoder error is to adopt auxiliary position sensing devices. A potentiometer is used at an auxiliary position sensing the device motion because it has no complex active component inside.

Potentiometers are installed to mirror the absolute encoders on the IDs to provide a robust gap and phase measurement for the protector system as shown in Fig. 5, even if the motion control encoders fail.

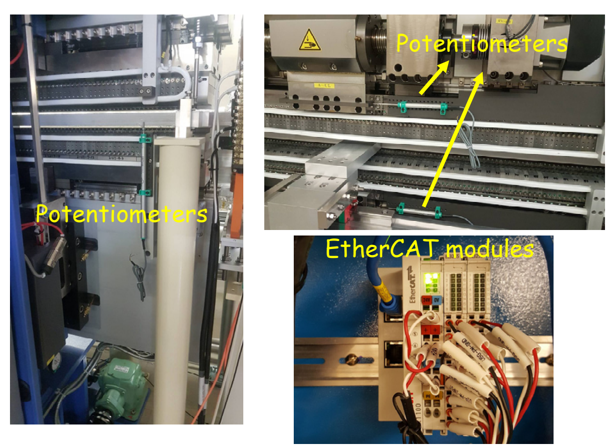

Figure 5: Potentiometers are installed to mirror the absolute encoders on the EPU48 and EPU46.

The reading module for the potentiometers is based on the EtherCAT device [6]. The hardware configuration for potentiometers of the EPU48 and EPU46 is shown in

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Fig. 6. The Beckhoff EL3255 (potentiometer reader) module and potentiometer (GEFRAN, PZ-12-S-200 for Gap, PZ-12-S-075 for Phase) are installed at the ID [7]. After cross-calibration of potentiometer with the SSI encoders, the auxiliary absolute position can be used to crosscheck the absolute SSI encoder health for malfunction protection purpose.

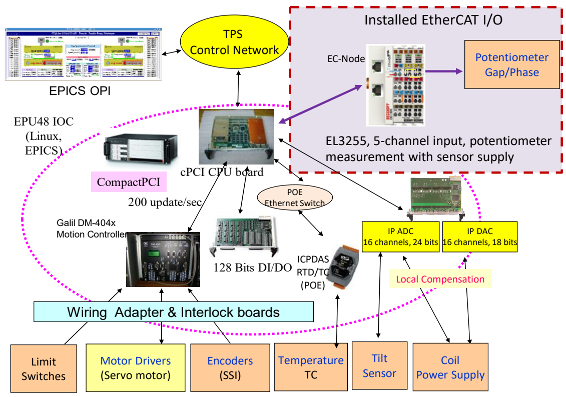

Figure 6: The hardware configuration for potentiometer of the EPU48 and EPU46.

The graphical user interface (GUI) is implemented by using EPICS EDM and Fig. 7 shows the main page for the EPU46. The right side shows encoder status which are bypass, all pass and gap or phase of encoder no update. If the encoder value has not been updated, the protection program can halt the motion of any axis by executing the abort motion command within a few milliseconds. The trip state can only be reenergized if all of the encoder errors are cleared or overridden. The flow chart for encoder error detection and aborting ID motion is shown in Fig. 8. A protection process is developed to compare the position from two sensors, if the difference is too large, the abort motion command will be sent to the motion controller to stop the motor driver.

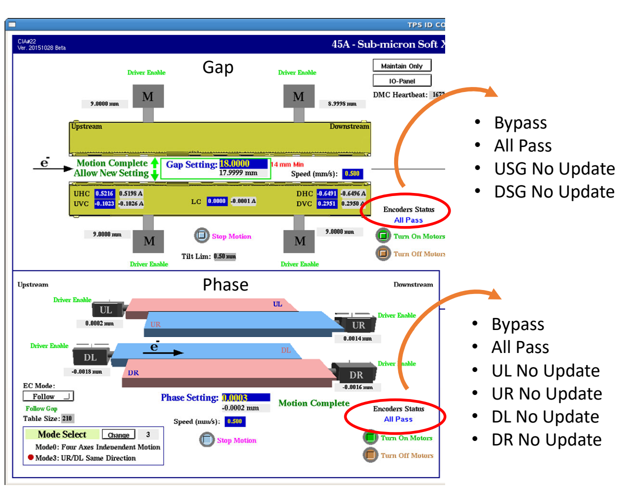

Figure 7: GUI of the EPU48.

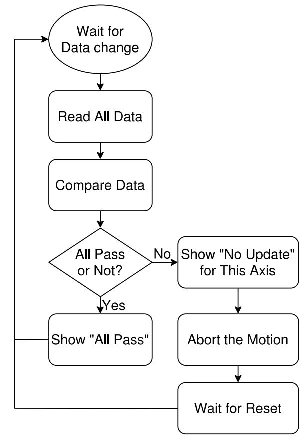

Figure 8: Flow chart for encoder error detection and abortion of ID motion.

CURRENT STATUS

Basic functionalities for the detection of encoder errors has been implemented and tested. EtherCAT EPICS IOC and GUI are developed for the EPU48 and EPU46. The failure rates of encoders are reduced after the encoders are covered by lead shielding. Preliminary tests show its efficacy for early detection of encoder errors and termination of motion.

Moving the encoders away from the electron beam axis to overcome radiation problems will be done during TPS phase II IDs for the EPU66 and EPU168. Potentiometers will also be installed to crosscheck the absolute encoders on the TPS phase II EPU ID to provide a robust gap and phase measurement for the protection system.

We have yet to establish whether we will see long term radiation damage of these encoders. Some of them have been in the ring since 2015. Next, we will develop a program to automatically recover absolute encoder soft errors.

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