LINAC COHERENT LIGHT SOURCE (LCLS) UNDULATOR LINE CONTROL SYSTEM*

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Abstract

The 132-meter-long Linac Coherent Light Source (LCLS) undulator line consists of 33 identical undulator segments situated in a co-linear fashion. An Experimental Physics and Industrial Control System (EPICS)-based turnkey control system has been designed and delivered to the LCLS project by the Advanced Photon Source (APS). The control system is responsible for a myriad of motion and feedback channels for each segment including two linear and five nonlinear motions with micron-level accuracy, numerous absolute position readbacks, and multiple temperature sensors. With the large distance covered in the undulator line tunnel, it was decided to distribute the controls duty to multiple instances of control hardware located at each segment within the tunnel itself. A detailed description of the control system and its operation is reported.

INTRODUCTION

The 132-meter-long undulator line of the LCLS [1] at the Stanford Linear Accelerator Center (SLAC) has 33 segments. Supported on a girder, each segment consists of an undulator, a quadrupole, a beam position monitor (BPM), and ancillary components. Girders are supported on 5-axis cam mover positioning systems. The undulator strongbacks are supported on 2-axis translation systems to adjust and move the undulators horizontally in and out of the beam independently as needed [2-6].

Due to the non-linear nature of the cam mover system, the angular position of each cam mover is monitored by an absolute angular position sensor. The girder position is monitored by six absolute linear position sensors. The relative translation position of the undulator to the girder is monitored by two absolute linear position sensors.

Since the distance between the undulator equipment building and the furthest girder is over 150 meters, field input/output control (IOC) systems were selected to host motion control. Each segment is equipped with a field IOC that is capable of handling 7 motion axes, 13 absolute position feedbacks, and 12 temperature sensors. All 33 IOCs are seamlessly networked. All undulator line positioning applications are EPICS-based to ensure the integrity and the efficiency of the alignment operation.

SYSTEM DESCRIPTION

The core of the LCLS undulator line positioning control system comprises 33 field IOCs. Each undulator segment is equipped with an IOC. Each IOC is a VME crate with a MVME31006E control card from Emerson Network Power and an Acromag AVME-9670 IndustryPack (IP) card carrier that hosts an analog-to-digital (A/D) IP module with 16-bit resolution. An 8-port RS-232 module and an 8-bit optically isolated digital input/output module are also hosted on the same IP carrier.

The peripherals of each IOC comprise the positioning control system and the positioning feedback system. The control system has seven motors that drive the positioning systems. The motors are SmartMotor servomotors from Animatics Corporation, with the motor control integrated in the back of each motor including an RS-232 serial interface. Two motors drive the ID in and out of the beamline translation positioning system. The other five motors operate the girder 5-axis cam mover positioning system. The motors are connected to the IOC via individual RS-232 serial interfaces.

The feedback system has five angular absolute position feedback sensors that monitor the cam mover angular positions and eight linear absolute position feedback sensors that monitor the girder and the ID positions. The angular absolute position feedback sensors are P2200 series angular potentiometers from Novotechnik U.S., Inc. The angular sensors are mounted on each of the cam movers. The sensors have unrestricted continuous rotation with 345 degrees of electrical travel. The actual working range of the cams is 180^{o}. The sensors have a repeatability of 0.004^{o} that translates to better than 0.15 microns in linear scale at the “worst” positions with a 2mm cam mover eccentricity. The sensors are excited with an AD584 precision voltage reference from Analog Devices. Each sensor is connected to a 16-bit A/D channel of the IOC. Long-term excitation drift is compensated by the voltage reference normalization. With a 2mm cam mover eccentricity, the linear resolution is better then 0.2 microns.

The linear absolute position feedback sensors are TR series linear transducers from Novotechnik U.S., Inc. Six TR-10 linear transducers with 10mm measurement range are used to monitor the girder position reference to the supports. With the 16-bit A/D converters, the resolution of the absolute position feedback sensors is better than 0.2 microns. The voltage noise of the DC power source is <50μV p-p. With a low-pass digital filter programmed in the A/D EPICS driver, the stability of the sensors is ~0.2 microns.

Two TR-100 linear transducers with 100mm measurement range are mounted on the ID translation stages to monitor the ID position reference to the girder. Due to the nature of the twin screw-drive linear translation system, a precision comparator circuit was

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designed to monitor the difference between the two transducers. If the difference becomes too great, a series of alarms is generated with the final outcome being removal of motor power for a relatively large skew measurement. The settings are user configurable via front-panel trim potentiometers located on a custom-designed module within the controls rack.

Twelve precision Platinum RTD sensors are placed at various positions on each undulator segment. The signals are linearized and read into the IOC via the ADC interface.

The field IOC along with the motor power supply and accessories are mounted in a rack enclosure and positioned underneath the girder of each undulator segment.

SEGMENT ALIGNMENT ALGORITHM

A quadrupole magnet is mounted at the downstream end of each girder. In order to minimize the quadrupole center shift during undulator roll-out, the cam support system has the following configuration: at the upstream end of the girder there is a combination of a single cam (cam 1) and a double cam set (cams 2 and 3); at the downstream end there is one (expanded) double cam set (cams 4 and 5). See Figures 1 and 2 for illustration. The r_i are the eccentricities of the cams and the β_i the absolute wedge angles, where i=1, 2, 3, 4, and 5. The surface normals at the cam-wedge contact points of cams 3, 4, and 5 intersect the beam axis Q_d. X_1 and X_{23} are the horizontal distances between Q_d and the center of cam 1 (M_1) at its "home" positions, and Q_d and P_1, respectively, where P_1 is the cross point of the wedge surface normals of M_2 and M_3.

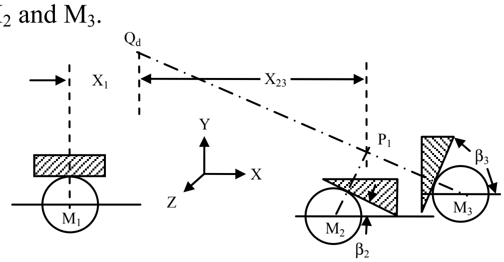

Figure 1: Cam and wedge block arrangement at the upstream end, looking upstream.

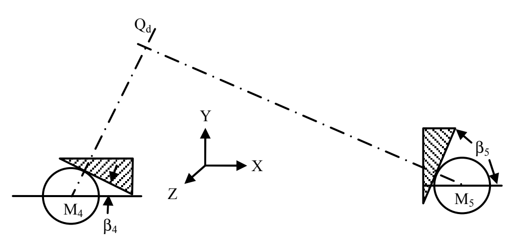

Figure 2: Cam and wedge block arrangement at the downstream end, looking upstream.

With the cam mover initial angular positions set at the zero (home) positions, cam angular positions are defined by:

$$\sin\phi_1 = \frac{Y_{us} + \gamma \times X_1}{r_1}\,; \tag{1}$$

$$\sin\phi_2 = \frac{(Y_{us} - \gamma \times X_{23}) \times \cos\beta_2 + X_{us}\sin\beta_2}{r_2}\gamma\,; \tag{2}$$

$$\sin\phi_3 = \frac{(Y_{us} - \gamma \times X_{23}) \times \cos\beta_3 - X_{us}\sin\beta_3}{r_3}\,; \tag{3}$$

$$\sin\phi_4 = \frac{Y_{ds}\cos\beta_4 + X_{ds}\sin\beta_4}{r_4}\,; \tag{4}$$

$$\sin\phi_5 = \frac{Y_{ds}\cos\beta_5 - X_{ds}\sin\beta_5}{r_5}\,, \tag{5}$$

where ϕ_i are readings from the absolute angular sensors reference to their "home" positions; X_{us}, Y_{us}, X_{ds}, and Y_{ds} are X and Y upstream and downstream destination variables; and γ is the girder roll angular variable.

SOFTWARE

The operating system (OS) running on the MVME31006E field IOC VME control card is RTEMS 4.9. EPICS base 3.14 runs on each IOC. The motor record and corresponding device support and driver support are used to control the motors via an EPICS Asyn module through the serial ports. Seven motor records and 26 analog input (ai) records are loaded to control the motions and monitor the position and temperature sensors, respectively. Some other soft ai and calcout records are used to implement the girder mover algorithm.

Over 300 EPICS process variables (PVs) were implemented for each segment to handle the system calibration, provisioning, control, and monitoring. Figure 3 shows an EPICS Editor/Display Manager (EDM) Graphic User Interface (GUI) view of the system for a single segment.

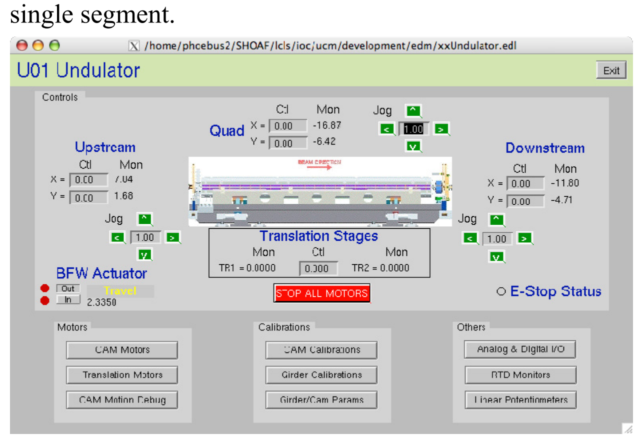

Figure 3: An EDM GUI view of the control system for a single segment.

Users can access each individual undulator segment via the provided EDM GUI view of the control system or address a number of segments or even the whole undulator line through EPICS PVs over the network via high-level scripts/applications.

OPERATION

Operation of the undulator line control system involves the system position calibration, position setting, and position monitoring. After initial installation, reset, or replacement of any absolute rotary or linear sensors of a segment, that segment's positioning system must be calibrated. This can be accomplished with the girders installed. Girder position settings are defined by the girder's upstream and downstream support translation and roll rotation along the Z direction. Once the system is calibrated, motion requests for new positions are translated into the cam positioning parameters, and the girder is then repositioned by adjusting the cam angles according to equations (1) - (5). ID position settings, referenced to the girder, are defined by the twin screw-drive linear translation system.

Position settings are carried out by setting the position variables of each segment through EPICS PVs over the network. The motions can be executed in parallel throughout all the segments. Segment local position monitoring systems are responsible for segment local position monitoring reference to the girder supports. Girder position is monitored locally in real time by six linear sensors. Five of them are independent. The sixth one is redundant if the girder is a perfect rigid body. Otherwise, the redundancy yields the information of girder deformations.

The ultimate position reference is provided by the undulator line "global" position monitoring alignment systems. The "global" position monitoring systems are the hydrostatic leveling system (HLS) and the wire positioning monitor system (WPM), which are used as absolute position reference of the segments [1].

CONCLUSION

An EPICS-based undulator line positioning control system has been developed and built at the APS and delivered to SLAC. Detailed system layout and positioning algorithms have been given, including the calibration and validation procedures. The system has been successfully tested at SLAC during the beam commissioning [7].

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