PERFORMANCE OF PRODUCTION SUPPORT AND MOTION SYSTEMS FOR THE LINAC COHERENT LIGHT SOURCE UNDULATOR SYSTEM*

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Abstract

The Linac Coherent Light Source (LCLS), now being commissioned at the SLAC National Accelerator Laboratory (SNAL) in California [1], and coming online for users in the very near future, will be the world's first x-ray free-electron laser user facility. Design and production of the undulator system [2-5] was the responsibility of a team from the Advanced Photon Source (APS) at LCLS-Partner Argonne National Laboratory (ANL). A sophisticated, five-axis, computer-controlled support and motion system (SMS) positions and stabilizes all beamline components in the undulator system. The SMS also enables undulators to be laterally retracted from the beam by 80 mm without disturbing the rest of the beamline components. A brief overview of the SMS follows, together with achieved performance data from the first-article production SMS unit at Argonne.

INTRODUCTION

The Linac Coherent Light Source (LCLS), now being commissioned at the SLAC National Accelerator Laboratory (SNAL) in California, and coming online for users in the very near future, will be the world's first x-ray free-electron laser user facility. A team from the Advanced Photon Source (APS) at LCLS-Partner Argonne National Laboratory (ANL) was responsible for design and production of the undulator system, in collaboration with LCLS. A sophisticated, five-axis, computer-controlled support and motion system (SMS), seen in Figure 1, positions and stabilizes all beamline components in the undulator system. The SMS also enables undulators to be laterally retracted from the beam by 80 mm while the remaining supported beamline components are, within tolerances, unaffected. Industrial production of 38 SMS systems with the precision dimensions and tight tolerances required a focused technical effort, high quality standards, attention to detail, and an equally unwavering commitment to excellence on the part of our fabrication and assembly vendors [6, 7].

DESIGN FEATURES

The stability and reproducibility requirements that must be met by the undulator SMS are very tight, thus system design was quite challenging.

The SMS consists of three major components: two sand-filled, insulated steel support pedestals, thick steel intermediate plates with camshaft movers, and a rigid steel girder with two precision translation stages. The vacuum chamber, quadrupole magnet, beam finder wire (BFW), beam position monitor (BPM), beam loss monitor (BLM), and other vacuum and diagnostic components are supported and positioned by the girder, in addition to the undulator that is mounted on its translation stages. The weight of the undulator (~1000 kg) is transferred through the translation stages to hardened-steel wedges attached to the underside of the girder directly below the stages. The undulator's weight is then transferred from the wedges to the camshaft mover (CSM) bearings, beneath which adjustable screws direct this load to the top plate of the pedestal. The top plate is attached to the pedestal with four rigid rods to allow for initial height adjustment. Five camshaft movers, with 1.5-mm eccentricity, allow for precise remote positioning, adjustment, and beam-based alignment of the girder in x, y, pitch, roll, and yaw via the control system. An undulator can be retracted partially or completely out of the beam by 80 mm on its stages.

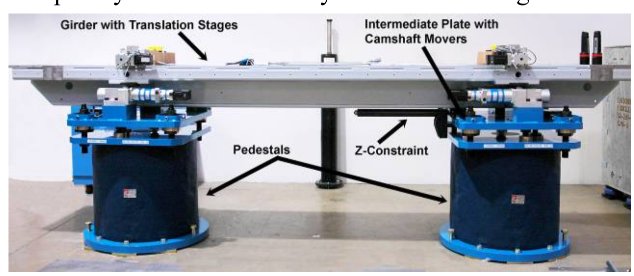

Figure 1: Complete SMS, showing all major components.

In addition to high precision and stability, ensuring the safety of all personnel and of the equipment was of paramount importance. Personnel safety and equipment protection were incorporated into the design from the very beginning. Designs were reviewed by SNAL for compliance with applicable earthquake standards. All girder and undulator motion is monitored and supported by potentiometers and redundant limit switches.

Tight tolerances between the undulator and the vacuum chamber require additional protection when the undulator is moved on its translation stages. The redundant limit switches facilitated implementation of three levels of protection, including software warnings, software limits, and finally power cuts to the motors. A robust mechanical hard stop is the forth element in the protection chain. In the extremely unlikely event that the other measures fail, the hard stop is mechanically able to stop the motion and prevent damage. Two industry-standard emergency stop buttons are integrated into each module. Pressing either red button stops electrical power to all motion systems. The girders are held longitudinally during alignment by

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"Z" constraints that do not restrict the camshaft movers.

A prototype single-undulator module was assembled at Argonne to measure its performance and to help develop assembly and installation procedures. While the initial design met almost all of the specifications, results of our tests showed that some additional strengthening of the supports and girder was necessary. Calculations and mechanical simulations guided the design improvements.

The first production SMS unit, a photograph of which is shown in Figure 2, was installed and assembled in the long-term test area at APS. This SMS was integrated using first-article production units of all of the major components. The performance of this production module was extensively studied, and results show that the systems meet the requirements. The assembled production module was also used to develop safe assembly, alignment, and repair procedures to be used at or as a basis for LCLS's own procedures.

Figure 2: Production SMS in the APS long-term test area.

TESTS AND RESULTS

Two major categories of performance tests were carried out: 1) displacement of the girder on its camshaft movers and 2) 80 mm lateral displacement of the undulator in and out of the beamline on its translation stages.

Keyence confocal laser displacement sensors [8] were securely attached to rigid pedestals bolted to the concrete floor, and data were measured off of precision-ground reference cubes mounted at beam center on the BPM/quadrupole (downstream end) and BFW (upstream end) as shown in Figure 3. Keyence sensors and potentiometers, one of which is shown in Figure 4, were monitored while particular series of motion commands were executed many times. These tests typically ran overnight or over a weekend, lasting for many hours. Temperature was monitored at 12 points on the undulator, girder, vacuum chamber, diagnostics, pedestals, and in the air. The long-term test area is an open space on the APS's experiment floor and is not controlled to better than ±1°C.

The first tests to be carried out were the girder displacements, for which typical results are shown in figure 5. The camshaft movers under the girder, (see figure 4) were directed to move the BPM/quadrupole center radially out to a point 500, 100, 5, and finally only 2 microns away, then back to zero, and then radially out to that point plus 10 degrees, and so on around the complete circle. Figures 5a and 5b show the 500-micron motion and 100-micron motion at the upstream and downstream ends superimposed on the same graph. Figure 5c shows the upstream end when directed to move out to a 5 micron radius, and Figure 5d shows the same position when directed to move out to only 2 microns.

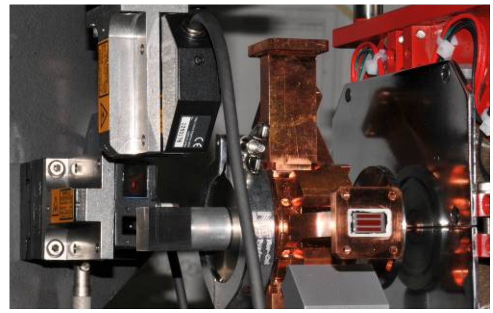

Figure 3: Two Keyence sensors and precision cube.

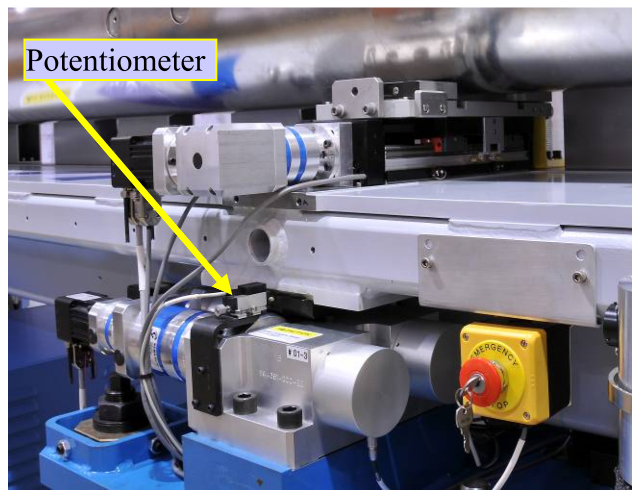

Figure 4: The girder, an E-stop button, a double camshaft mover with motors and potentiometer on an intermediate plate, and a translation stage with motor are shown.

Data points are enlarged for viewing, and the error bars and dispersion are smaller than the dots on the graphs. Each measurement series was repeated forty (40) times. Reproducibility is accurate to within a micron or less, and backlash is a couple of microns at worst. The number of cycles represented by these tests is greater than any one of these systems will experience in the lifetime of LCLS.

Upon completion of the girder displacement studies, undulator translation studies were carried out. The undulator was moved back and forth by 80 mm, in and out of the beam on its translation stages a total of ten times. Results are shown in the graph in figure 6, where each "dot" contains ten separate data points. In the worst case, when the undulator is moved completely away from the beam centerline, the BPM and quadrupole centers shift by 22 microns horizontally and 12 microns vertically, but return back to within 2 microns after the undulator moves back in. Data points are enlarged for viewing purposes.

Table 1 is a summary of major physics performance requirements and achieved results.

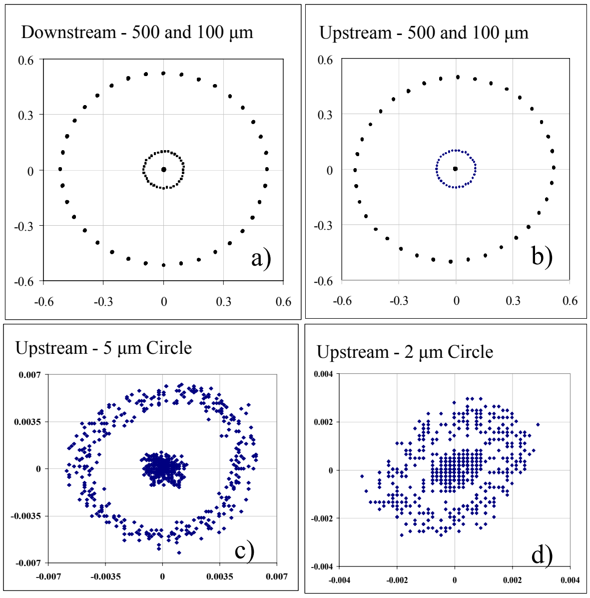

Figure 5: Girder displacement tests show excellent SMS reproducibility, repeatability, and stability.

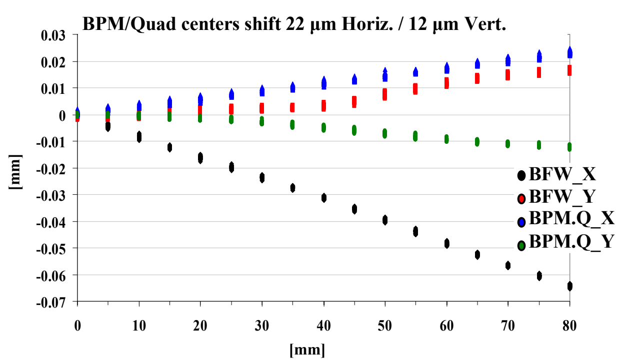

Figure 6: BPM and quadrupole magnet centers shift 22 microns horizontally and 12 microns vertically when the undulator is moved out of the beamline by 80 mm, but return to zero within two microns when it moves back in.

CONCLUSIONS

Thirty-eight micron-level-precision support and motion systems were designed, prototyped, tested, fabricated, and delivered. One of the production systems was retained for performance testing and procedure refinement. The rest were delivered for installation and commissioning in the LCLS tunnel. Extensive testing was performed at Argonne to assess the stability, reproducibility, and accuracy of the production systems. Our tests show that all performance requirements were met or exceeded.

Preliminary testing, after installation of these supports in the LCLS tunnel and extremely successful initial beam commissioning, supports our results.

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Table 1: Critical Specifications and Achieved Results

SMS Parameters	Spec.	Meas.	Unit
Quad position repeatability	±7	±1	µm
Short-term BPM & Quad stability	±2	±1	µm
Long-term BPM & Quad stability	±5	±3	µm
Min. quad motion range radius	1.0	1.0	mm
Quad center manual adj. range	±2	±2	mm
Quad center manual adj resolution	2	2	µm
Quad position change in roll-out	±25	-0/+22	µm
Quad pos. reproduced after roll-out	±2	±1	µm
BPM transverse change in roll-out	±25	-0/+23	µm
BPM pos. reproduced after roll-out	±2	±1	µm
Horiz. undulator repeat in roll-out	±10	±5	µm
Vertical undulator repeat in roll-out	±5	±2	µm
Max. undulator roll-out duration	60	60	s

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