MAGNETS, SUPPORTS, AND CONTROLS FOR THE LINAC COHERENT LIGHT SOURCE (LCLS) UNDULATOR SYSTEM*

J. Collins, M. Jaski, G. Pile, S. Sasaki, S. Shoaf, J. Stein, E. Trakhtenberg, I. Vasserman, M. White, J. Xu, ANL, Argonne, IL 60439, U.S.A.

Abstract

The LCLS [1,2], now under construction at the Stanford Linear Accelerator Center (SLAC) in California, will be the world's first x-ray free-electron laser when it comes online next year. Design and production of the undulator system is the responsibility of a team from the Advanced Photon Source (APS) at Argonne National Laboratory (ANL). Forty 3.4-m-long high-precision undulators, 37 laminated quadrupole magnets, plus 38 support and motion systems with micron-level adjustability and stability have been constructed and delivered to SLAC. Argonne's computer control and monitoring system enables the undulator girders and all components mounted on them to be accurately positioned. An overview of these systems will be presented, including achieved results.

INTRODUCTION

The LCLS is now under construction at the Stanford Linear Accelerator Center (SLAC) in California, and will be the world's first x-ray free-electron laser when it comes online next year. Design and construction of the LCLS are accomplished primarily by a partnership of three US national laboratories: Argonne National Laboratory (ANL), Lawrence Livermore National Laboratory (LLNL), and SLAC. A team from Argonne's Advanced Photon Source was responsible for design and construction of the high-precision undulator system, including the undulator and quadrupole magnets, vacuum system, beam diagnostics, ultra-stable support and motion system, and computer control and monitoring of the undulator system. At the time of this paper, all magnets and supports, together with the complete undulator controls system, are delivered. Installation in the LCLS tunnel is in progress.

MAGNETS AND SUPPORTS

Undulators

Forty planar-hybrid, fixed-gap undulators were designed for LCLS by the Argonne team [3,4], and were optimized for industrial mass production. The most important undulator physics requirements are listed in Table 1. Undulator assembly was accomplished ahead of schedule and with significant cost advantage. Bidders on the fabrication and assembly contracts were prequalified to ensure that they were capable of performing the job safely and correctly. The Argonne team devoted time up front to procedure development, vendor safety training, and completion of the necessary documentation. Vendor oversight, communication, and QA were continuous and thorough throughout the duration of the effort. The final undulator was ready 27 months after award of the first contract. The first undulator from each of the assembly vendors [5,6] was magnetically tuned and mechanically verified at Argonne. All remaining undulators were delivered directly to SLAC for final tuning and fiducialization. Average peak fields of all undulators were measured at factory acceptance, using a portable Hall probe, as shown in Figure 1.

Table 1: Undulator Physics Requirements.

Parameter	Value	Units
# of 3.4-m-long und. segments	33 + 7	
Total installed undulator length	131.520	m
Min. expected undulator sys. life	20	years
Undulator period length	30.00±0.05	mm
Undulator gap height	≥ 6.8	mm
Wiggle plane	horizontal	
Horiz. und. seg. good field region	±5.0	mm
Vert. und. seg. good field region	±200	μm
Total pole cant angle	4.5	mrad
Phase slippage distance of 113×2π	3.656	m
Phase slip. tolerance (@ 1.5 Å)	±175	mrad
Max. acc. seg. ph. err. (@ 1.5Å)	±175	mrad
Earth mag. field comp. error (rms)	1×10^{-5}	T
Abs. 1st field int. along und. seg.	$<40\times10^{-6}$	Tm
Abs. 2nd field int. along und. seg.	$<50\times10^{-6}$	Tm^2
Undulator system temp. range	20.00±0.56	°C

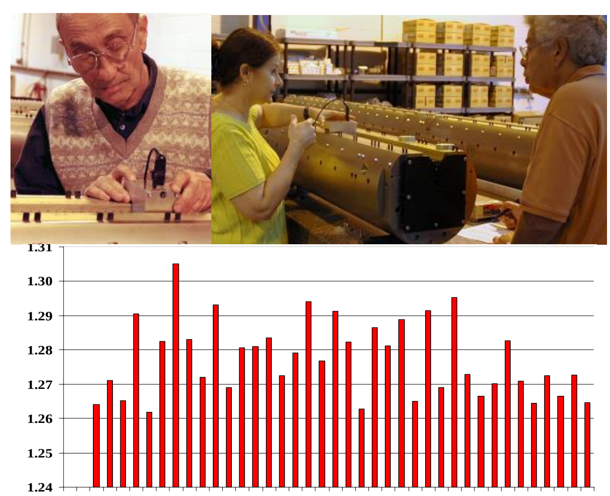

Figure 1: Factory acceptance of an LCLS undulator (top); average peak fields per undulator at acceptance (bottom).

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Quadrupole Magnets

Each undulator girder has a quadrupole magnet with horizontal and vertical correctors. The magnet was designed for excellent field quality and mechanical stability. It is air-cooled to avoid the need to supply water in the undulator tunnel. The magnet was also designed for low power dissipation, since the total dissipated-power budget from all sources is 50 W/meter, including lighting. The 40-lb quadrupole is supported by a stable, compact, rigid stage that provides for vertical and transverse adjustment of the magnet. The stage has a travel range of ±3 mm in both directions and a precision of 2 microns. The quadrupole magnet and support parameters are listed in Table 2. Figure 2 shows photographs of the quadrupole magnet (left) and its support stage (right).

Table 2: Major Quadrupole Magnet Parameters.

Quadrupole Parameter	Value	Unit
Nominal integrated quad gradient	3.00±0.03	T
Maximum integrated quad gradient	4.0	T
Trim strength range	$\pm3\times10^{-4}$	Tm
Trim stability	$\pm3\times10^{-7}$	Tm
Trim settability	$\pm1.5\times10^{-6}$	Tm
Center stability after fiducialization	±10	µm
Center stability @ ±20% grad. chng	±3	µm
Center stability - short term (1h)	±1	µm
Center stability - long term (24h)	±3	µm
Grad. stability - long term (24h) rms	0.25	%
Roll tolerance	±20	mrad
Pitch tolerance	±15	mrad
Yaw tolerance	±15	mrad

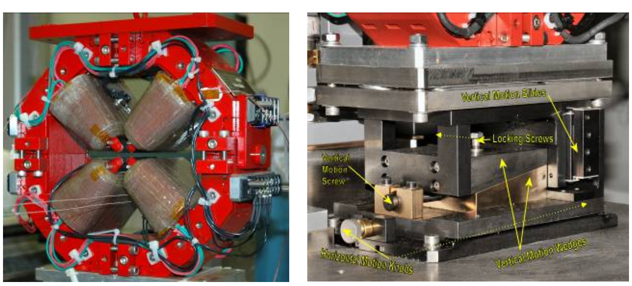

Figure 2: End view of the quadrupole magnet and stage.

Support and Motion System (SMS)

The undulator system SMS is shown in Figure 3 [7]. It consists of three major components: pedestals; intermediate plates with camshaft movers; and a girder with two translation stages onto which the undulator, vacuum chamber, quadrupole, beam position monitors, and various vacuum and diagnostic components are mounted. Figure 4 is a photo of the girder cross section.

An undulator is 305 mm in diameter, 3400 mm long, and weighs 1000 kg. The 1000-kg weight of the undulator is transferred through its translation stages to hardened-steel wedges that are attached to the underside of the girder directly below the stages. The undulator's weight is further 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 five camshaft movers, each with an eccentricity of 1.5 mm, allow for precise horizontal and vertical positioning and adjustment of the girder. The pedestal's top plate is attached to the pedestal with rods that allow for initial height adjustment.

A double CSM and a single CSM are located adjacent to each other on the upstream pedestal. Two single CSMs, acting as a double CSM – where the cams are spread apart for added stability – are located on the intermediate plate of the downstream pedestal, as shown in Figure 5.

Undulators can be remotely retracted out of the beamline by 80 mm using the translation slides. The tolerances on precision, short- and long-term stability, and reproducibility are quite stringent as shown in Table 3. The complete SMS was tested for many hundreds of hours to ensure that stability, repeatability, and reproducibility met specifications.

Table 3: Major Support and Motion System Requirements.

SMS Requirements	Value	Unit
Quad. position repeatability	±7	µm
Short-term BPM & quad stability	±2	µm
Long-term BPM & quad stability	±5	µm
Min. quad motion range radius	1.0	mm
Quad center man. adj. range	±2	mm
Quad center man. adj. resolution	2	µm
Quad position change in roll-out	±25	µm
Quad reproducibility after roll-out	±2	µm
BPM transverse change in roll-out	±25	µm
BPM reproducibility after roll-out	±2	µm
Horiz. und. repeatability in roll-out	±10	µm
Vert. und. repeatability in roll-out	±5	µm
Maximum und. roll-out duration	60	s

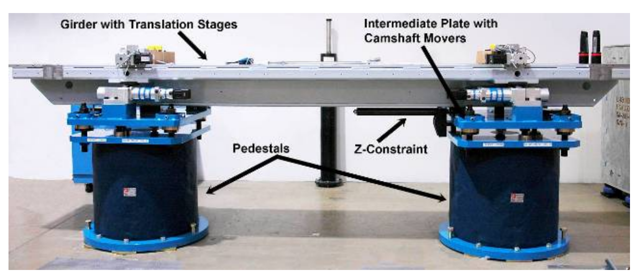

Figure 3: The undulator SMS is shown, including pedestals, intermediate plates with camshaft movers, and the girder on its translation stages.

Figure 4: A cross section of the support girder mounted on the intermediate plate.

Figure 5: The undulator is mounted on a translation slide that is attached to the girder. The double CSM is shown below the girder, mounted on the intermediate plate.

CONTROLS SYSTEM

The LCLS Undulator Control System is responsible for micron-accuracy positioning of each undulator segment within the undulator hall. A variety of commercial-off-the-shelf and custom hardware was chosen and configured into 33 identical, modular subsystems. Each rack contains a self-contained set of control hardware and runs a unique instance of the EPICS-based control system. Components communicate via wired Ethernet. The undulator system controls rack can be seen below the girder in Figure 6.

Each control module controls five camshaft movers and two translation slides. Together, they can position the girder with micron accuracy with five degrees of freedom including x and y, pitch, and roll and yaw where the z-axis is oriented along the undulator axis. The translation slides allow withdrawal of the undulator from beam center by 80 mm.

The undulator is protected against over-travel by redundant sets of software and hardware limits. Transverse undulator motion is constantly monitored to ensure synchronicity of the two translation stages within 50 microns. Motion control is supported by six 0.5-inch-travel spring-loaded potentiometers with a resolution of 0.13 microns. Four potentiometers provide vertical position data and two provide horizontal position data.

The Undulator Control System is also responsible for monitoring the temperature at 12 points along each undulator and for controlling the beam finder wire diagnostic.

A complete undulator module was assembled from prototype and 1st-article components, including pedestals, intermediate plates with camshaft movers, controls rack, cabling, electronic components, a girder with translation stages, a quadrupole, a BPM, a wire position monitor (WPM), and an undulator with mu-metal shield. The module was thoroughly tested for hundreds of hours at the Advanced Photon Source at Argonne in order to demonstrate that the system, as designed, met all specifications. Some adjustments were made to the final production supports to make them even more rigid. Figure 6 is a photograph of the final undulator module and controls system at Argonne, assembled from first-article production components.

Figure 6: The complete single-undulator module at Argonne.

SUMMARY

Forty undulators, 37 quadrupole magnets, 38 support and motion systems, and complete undulator system controls were designed, prototyped, tested, constructed, and delivered to SLAC. Final undulator tuning and fiducialization are in progress and proceeding well at SLAC, and component installation in the LCLS tunnel is well underway.

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REFERENCES

[1] Linac Coherent Light Source (LCLS) Project homepage: http://www-ssrl.slac.stanford.edu/lcls/

[2] G. Pile et al., "Design and Production of the Undulator System for the Linac Coherent Light Source (LCLS)," these proceedings.

[3] E. Trakhtenberg et al., Proc. of PAC07, Albuquerque, NM, USA, July 2007, TUPMN100, p. 1148-1150; http://www.JACoW.org.

[4] I.B. Vasserman et al., Nucl. Instrum. Methods A575, 22 (2007).

[5] Hi-Tech Mfg., 4637 N 25th Ave, Schiller Park, IL, 60176, USA.

[6] Metalex Mfg., 5750 Cornell Rd., Blue Ash, OH, 45242, USA.

[7] E. Trakhtenberg et al., Proceedings of the 2008 MEDSI Conference, to be published in NIMA.