VACUUM AND BEAM DIAGNOSTICS FOR THE LINAC COHERENT LIGHT SOURCE (LCLS) UNDULATOR SYSTEM*

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Abstract

The LCLS, 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 vacuum and beam diagnostics is the responsibility of a team from the Advanced Photon Source (APS) at Argonne National Laboratory (ANL). The Argonne-provided components are: the internally polished 3.4-m-long aluminum extrusion vacuum chambers, a highly flexible bellows and its beam liner, a submicron-accuracy x-band cavity beam position monitor, a fixed-wire diagnostic for beam location, and a beam loss monitor system. These components are either being or have been constructed and delivered to SLAC for installation. An overview of these systems, including achieved results, will be presented.

INTRODUCTION

The Linac Coherent Light Source (LCLS) will be the world's first x-ray free-electron laser when it becomes operational in 2009. The LCLS is a US-DOE-funded project that is currently in the production and installation phase with some subsections in the commissioning phase.

The portion of the accelerator line that produces x-rays is the Undulator System. The 33 undulator assemblies, seen in Figure 1, are the heart of the LCLS free-electron laser with a total length of 131.52 meters. Within the Undulator System is a number of electron beam diagnostics and vacuum components. This paper will describe significant devices in those areas and performance of the production units.

VACUUM SYSTEM

Undulator Vacuum Chamber

The Undulator for the LCLS is a fixed-gap design having a 30-m-long period [1]. The overall length of the Undulator is 3.400 m and the chamber is 5.2 cm longer so that the vacuum connections are outside of the magnetic field. The undulator center is 25.8 cm above the top surface of the girder, and the undulator rests on linear slides to facilitate the 80-mm transverse motion needed to move the undulator away from the LCLS electron beam. The chamber must therefore be on its own support and have the ability to adjust its position in three axes and rotation in two axes. The chamber assembly is made of two elements: the welded chamber and the support-adjustment assembly. The support-adjustment assembly is based on a large aluminum box tube using 14 pair of adjusters that accurately place the chamber within the undulator gap.

The gap of the undulator is 6.8 mm, so the chamber was designed with an overall height of 6.1 mm to allow easy translation of the undulator without breaking vacuum. This required the walls of the chamber to be extremely thin in order to provide a 5-mm stay-clear aperture. To fulfill these requirements, an aluminum extrusion is the central piece in the 3.464-m-long assembly. Specially made EVAC flanges made of explosion-bonded 6061 aluminum and 316L stainless steel were carefully welded to each end of the assembly. The walls of the chamber were machined to a thickness of 0.45 mm [2].

The choice of aluminum for the main chamber material fulfilled a number of requirements for this application: vanishing magnetic permeability, the correct material to satisfy the AC resistive wall problems as a result of wake fields within the undulator, strength for maintaining

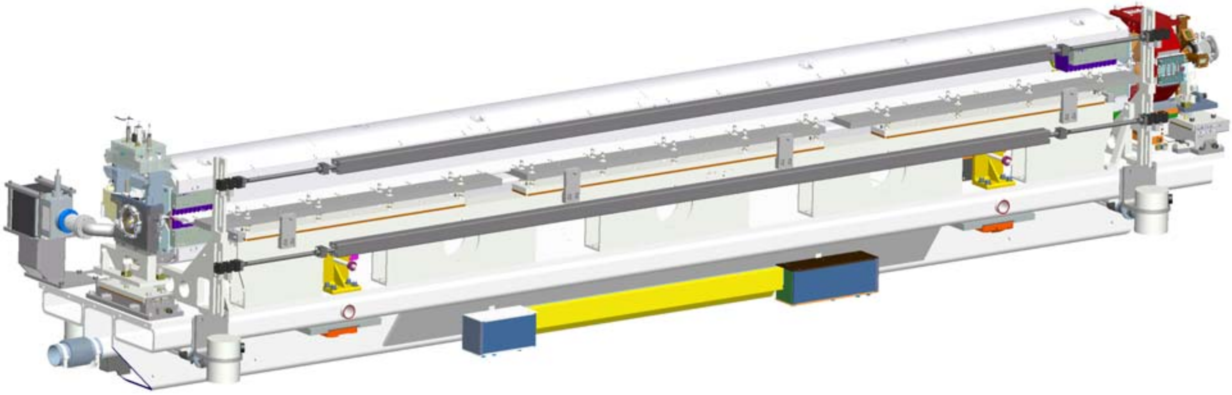

Figure 1: Undulator girder assembly.

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internal beam aperture with the atmospheric pressure load the thin walls, and the ability to be polished.

The problem of polishing the aluminum was neatly solved by using an extension of the abrasive flow machining process in which the aluminum oxide particles are pumped through the beam aperture to polish it. Figure 2 shows the test results [3] of the chamber interior polishing. The depiction of the surface finish is represented as the slope error of the surface and is shown in milliradians. Each chamber made by ANL is shown by a dot on the graph where the y axis is the slope error in the z direction, i.e., beam direction, and the x axis is the transverse slope error.. While a small number were outside of the acceptable region, there are 34 chambers that are fully acceptable.

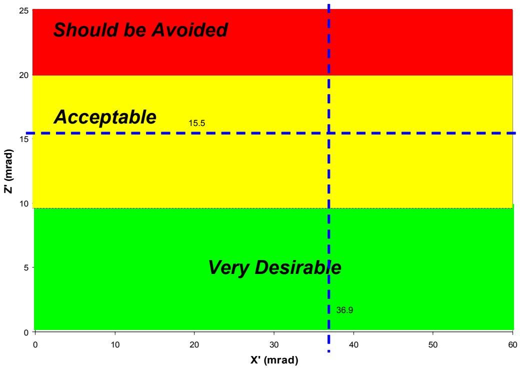

Figure 2: Chamber slope error.

The support-adjustment assembly for the chamber has the ability to precisely position the chamber and to minutely adjust the chamber straightness. Figure 3 shows the results of the in-house certification of the chambers and the straightness that could be achieved by using the adjustment mechanism on a laboratory granite table with height gauges.

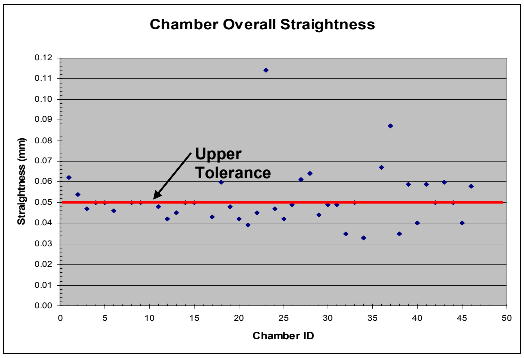

Figure 3: Chamber straightness.

Bellows Module

The bellows module is the vacuum's interconnect from one girder to the next. Since each girder is able to move independently, the bellows has to be able to withstand both transverse and angular displacements. The outer shell is made of a stainless steel welded bellows that is highly flexible. The inner 10-mm beam channel is made from 6061 aluminum with an inside diameter that was honed to a ~200-nm surface finish. The bellows was lab tested to confirm its ability to withstand 2000 cycles of ± 8 mm, ± 1°, and 500 cycles of a combined ± 9 mm and ± 0.8°.

Quad Spool

The spool that goes through the quadrupole magnet is made of a stainless steel tube with a bellows on each end attached to the EVAC flange. The tube is made of internally polished 316L stainless steel with a surface finish >125 nm. On each end is a short, four-convolution, 321 stainless steel bellows that is laser welded to both the tube and the flange. The assembly is finished with 4µm-thick internal aluminum plating.

EVAC Flange System

The EVAC flange system was selected due to its copper seal, short insertion length, bakeablity to 300°C, and single clamping bolt. The CeFix stainless steel flanges compress a copper seal to crush the inner diameter between 20° angled faces in order to affect a vacuum seal. Squeezing the flanges together is a clamp made of very low-magnetic-permeability nickel alloy, which uses one tightening bolt so that wrench interference is minimized.

Undulator Vacuum System

The undulator vacuum system is an all-metal system that uses metal seals throughout. The required average vacuum pressure of the system to conduct operations is less than 1×10^{-6} Torr. Given the extreme conductance limitations of the undulator vacuum chamber—on the order of 0.06 liter/second—all parts had to be designed and fabricated as if they were being used in an ultra-high-vacuum system.

The system is organized into 33 girder assemblies with a longer break between every third assembly. In that longer break is a spool with ports for a vacuum gauge and a pump-out valve.

The basic girder assembly is made up of five chambers: undulator vacuum chamber, quad spool, RFBPM, Bellows module, and beam finder wire. In the long breaks there is a long break spool that covers that drift space. All of the chambers use metal sealed flanges made by EVAC of Switzerland

DIAGNOSTIC SYSTEM

RF Beam Position Monitor (RFBPM)

The beam position monitor used in this application—an x-band cavity with x, y, and phase pickups in it—was chosen for its compactness and inherent resolution [4]. The specification [1] for this device required a resolution of better than 1 µm in both the x and y directions and 1-µm stability over a 1-hour period. The beam position monitor system, shown in Figure 4, is made up of three main components: the RFBPM cavity, the waveguide, and the down-converter electronics.

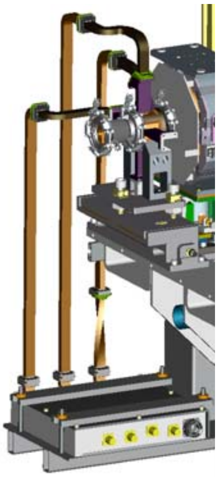

Figure 4: RFBPM assembly.

The RFBPM cavity is a copper brazement consisting of the dipole cavity for x-y measurements and a monopole cavity for phase measurements. In the dipole cavity there are five outputs attached to short waveguides. This design uses rf windows rather than coaxial feedthroughs to transmit the signal out of the cavity to the down converter in order to improve the robustness of the system and to aid stability. The 3-mm-wide cavity, used in both the dipole and monopole cavities, is precisely machined onto each end of the copper body and is polished to a surface finish of better than 100 nm to facilitate a Q greater than 3000. Brazed onto the body are end caps that have a similar surface finish. The end caps also include tuning pockets that allow the cavity to be tuned after it has been brazed At the end of the short waveguides are the rf windows, which allow the signal to pass through while also serving as a barrier between air pressure and vacuum.

Testing was conducted to determine the resolution and other critical parameters of the cavity. Figure 5 shows some of the results testing three BPMs at the Advanced Photon Source [5]. The resolution in the x direction is 0.36 μm and 0.27 μm in the y direction for this design.

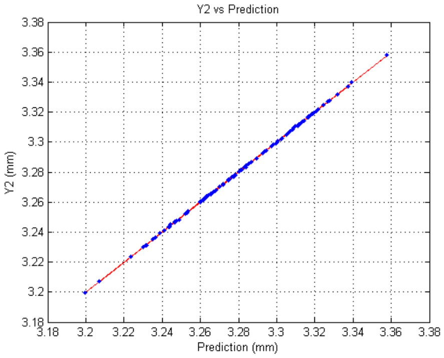

Figure 5: Resolution Y axis.

The down converter used in the LCLS contains a single-stage, three-channel heterodyne receiver, as shown in Figure 6. The signals transmitted from the x-band cavity are down converted to a 25-50 MHz intermediate frequency that is easily handled down the length of the undulator to the LCLS control system. The receiver is based on a commercially made down converter featuring a high-low gain (28/0 dB) to extend the dynamic range and an integrated self-test mode. Within the electronics assembly is a phase-locked local oscillator that allows the system to be controlled or to be in free-run mode.

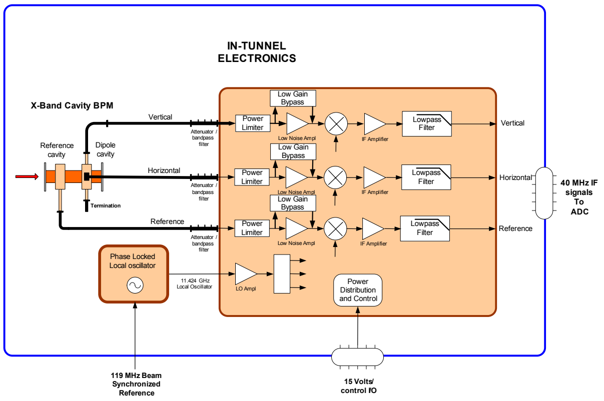

Figure 6: RFBPM system schematic.

Beam Finder Wire

The beam finder wire (BFW) is a device for locating the electron beam during maintenance of the girder assembly position. The downstream end of the girder will have an rf beam position monitor for measuring the position relative to the beam itself. The BFW performs a similar function on the upstream end by using a fixed pair of wires that intercepts the beam. The undulator motion system allows the movement of the x and y wires in and out of the beam to measure its location.

Figure 7: Beam finder wire assembly.

The BFW is a simple device that vertically moves a pair of wires—with precision and repeatability—into the measurement position. This assembly is shown in Figure 7. A ceramic card mounted to the end of the moving stage uses 30- to 40-μm-diameter carbon wires. This was designed and fabricated by a team at SLAC using their years of experience of building wire scanner diagnostics.

The specification [6] for the repeatability of the wire position is 30 microns vertically and 65 microns horizontally. This was achieved by the inherent accuracy of the commercially available kinematic plates that position the frame assembly. The ceramic card is attached to this frame assembly and, when it is inserted into the beam, the plate pair has the ability to control the location in three axes. Figure 8 is a sample of the results from the testing [3] of a completed BFW. All BFWs were cycle tested for 100 cycles at ANL to ensure that they continually met their specifications before being sent to SLAC for card assembly and girder installation.

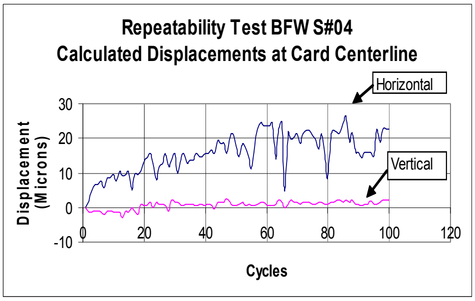

Figure 8: BFW repeatability.

Beam Loss Monitor

A beam loss monitor (BLM) system based on the detection of Cherenkov radiation is in development to limit radiation-induced demagnetization of the undulator permanent magnets. The BLM will provide beam-loss threshold detection as part of the Machine Protection System (MPS). The detector incorporates a large volume (30 cc), fused-silica Cherenkov radiator (see Figure 9) coupled to a photomultiplier tube (PMT). The output of the PMT is conditioned locally by a charge amplifier circuit and then digitized at the front end of the MPS rack electronics. During commissioning, the device will be calibrated by inserting a 1-micron aluminum foil into the beam, upstream of the undulator magnets. The present design calls for five BLM detector units to be distributed throughout the 33 undulator magnets.

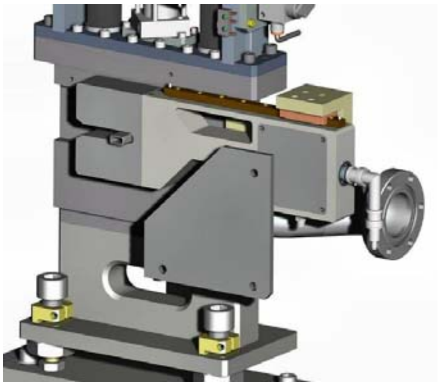

Figure 9: Beam loss monitor pickup.

CONCLUSION

All of the components are in production at this point. The extrusion chamber, chamber support assembly, bellows, quad spools, long break chambers, RFBPM support, and beam finder wire assembly have completed their full production run. The RFBPM is nearing the end of its production run of cavities and receivers.

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