ISBN: 978-3-95450-210-3 doi:10.18429/JACoW-FEL2019-THP068

LCLS-II EXTRUDED ALUMINUM UNDULATOR VACUUM CHAMBERS—NEW APPROACHES TO AN IMPROVED APERTURE SURFACE FINISH*

Greg Wiemerslage†, Patric Den Hartog, Jun Qian, Marion M. White
Argonne National Laboratory, 9700 South Cass Ave., Lemont, IL 60439, USA

Abstract

The Linac Coherent Light Source (LCLS), the world's first x-ray free-electron laser (FEL), became operational in 2009. The Advanced Photon Source (APS) contributed to the original project by designing and building the undulator line. Two slightly different variations of these chambers were required for LCLS-II: one for a soft x-ray (SXR) undulator line and one for a hard x-ray (HXR) undulator line. Because of the extremely short electron bunch length, a key physics requirement was to achieve the best possible surface finish within the chamber aperture. Improvements to our earlier fabrication methods allowed us to meet the critical surface roughness finish defined by rf impedance requirements. We were able to improve the surface finish from an average of 812 nm rms to 238 nm rms. The average longitudinal surface roughness slope of all chambers was to be less than 20 mrad. We achieved an average longitudinal surface roughness slope of 8.5 mrad with no chamber exceeding 20 mrad. In the end, sixty-four undulator vacuum chambers and alignment systems were delivered to SLAC National Accelerator Laboratory for the LCLS-II Upgrade project. Here we will report on the process improvements for the fabrication of these chambers.

NEW APPROACHES TO AN IMPROVED APERTURE SURFACE FINISH

The Linac Coherent Light Source (LCLS) at the SLAC National Accelerator Laboratory was the world's first x-ray free-electron laser (FEL) when it became operational in 2009 [1]. The Advanced Photon Source (APS) contributed to the project by designing and building the undulator line, including 41 undulator vacuum chambers [2]. The chamber's thin wall, small aperture, and aperture surface finish presented new production challenges. Although the aperture surface finish met requirements, schedule constraints at that time prevented us from further improving the polishing method beyond what was needed for the project. When presented with the opportunity to produce new undulator vacuum chambers for the new undulator lines of the LCLS-II upgrade, we were eager to improve the process and meet the technical requirements of the LCLS-II FEL.

Because of the extremely short electron bunch length, one of the key requirements from the LCLS-II physics specification was to achieve the best possible surface finish within the chamber aperture. The highly-polished aperture was achieved through a renewed collaboration with Engineered Finishing Corporation [2], the abrasive-flow machining vendor that polished the original LCLS vacuum chambers. Normally, the maximum aspect ratio for this process is 8/1, length/aperture. In this case, the process was modified to enable polishing of a small oval aperture extrusion (5 vertical mm × 11 horizontal mm × 4000 mm deep) with an aspect ratio ~700/1. The improved process permitted simultaneous polishing of two 4-m-long extrusions to meet the critical surface roughness finish defined by the radio-frequency impedance requirements—and with more consistent polishing results than before. The surface finish was improved from an average of 812-nm rms for an unpolished extrusion to an average surface finish of 238-nm rms after polishing. More importantly for the success of the project, the average longitudinal rms surface roughness slope (dh/dz, where h is the height of the peak) rms of all chambers was to be less than 20 mrad [3]; in fact, an average longitudinal surface roughness slope of 8.50 mrad was achieved, with no chamber exceeding 20 mrad. An example of the effects of polishing are best seen in comparing the unpolished samples and the after polishing samples of the same extrusion (shown in Fig. 1).

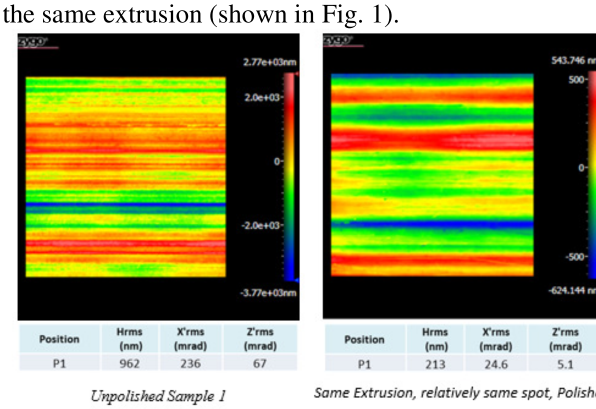

Figure 1: A comparison of unpolished (left) vs. polished surface roughness profiles (right).

To achieve these surface finish requirements, we modified our previously invented ninety-degree diverter. Our original polishing process only utilized one of the pistons of the abrasive flow machining equipment to push the polishing paste through the right angle diverter, through the extrusion aperture from one end, and allowed it to flow into a bucket at the other end. The paste was reloaded periodically as needed, which required constant attention from the operator, and the pressure of the paste on the aperture walls decreased down the length of the aperture [2]. The new diverter was built so that it now serves both the upper and lower pistons at the same time (see Fig. 2.) Second, we

* Work supported by the U.S. Department of Energy, Office of Science under Contract No. DE-AC02-06CH11357.
† wiemer@anl.gov

ISBN: 978-3-95450-210-3 doi:10.18429/JACoW-FEL2019-THP068

added a manifold that is attached to the opposite end of the extrusions being polished (see Fig. 3.) This combination of the new diverter and opposite end manifold allows two extrusions to be connected to the polishing machine at the same time (see Fig. 4), thereby reducing the production time by a factor of two. The polishing paste now slides back and forth through the extrusions as it should when the pistons move up and down. In addition, now that the pressure is consistent throughout both extrusions and the polishing machine is being utilized more as it was designed to be, the finish is more consistent down the entire length.

Figure 2: The right angle diverter showing flow direction.

Figure 3: The return end manifold.

Figure 4: Photo of the setup. Behind this setup is a second identical setup under an insulating blanket during processing. Also shown here are the roller brackets that also hold the heaters in place.

We still polish using three different grits and step down in coarseness to achieve the desired finish just as before [2]. The temperature of the extrusions being polished is elevated to 32°C to maintain a consistent and predictable viscosity each time. A fixture was developed that holds the heaters neatly in place over the apertures being polished and allows the extrusions to be rolled (see Fig. 4.) In the past, the extrusions were flipped end-for-end to equalize the head pressure at each end and flipped over to counter the effects of gravity on the polishing process. While still concerned about the potential effects of gravity on the polishing process, the equalized pressure no longer requires us to flip end-for-end. The rolling fixture allows the polishing operator to more easily reposition the extrusions half way through the grit cycle without disconnecting the manifold. As an improvement to the process, we finish the polishing with a cycle of gritless polishing paste to help clean out the remaining grit to reduce the possibility of residual grit left in the aperture and then rinse with a cleanser (Ensulve) to help remove any residue from the polishing paste before further processing of the extrusion takes place. In the past, the residual polishing paste sometimes proved difficult to clean from the aperture. These two additional steps helped minimize the number of extrusions that needed additional cleaning.

Final machining was performed after the abrasive flow polishing. The pressure of the media on the aperture walls is about 430 psi, and it would deform the thin 0.5-mm wall of the vacuum chamber that exists after machining. The thick un-machined extrusions provide ample strength to withstand the polishing pressure. Each extrusion was longer than the actual chamber length in order to have extra material from both ends for sampling to check the polishing quality. The Metrology Laboratory at the APS performed the surface finish measurements and calculated the slope error at three spots on each sample along and across the extrusion direction. Six extrusions of each type were cut to verify the surface finish in the center of the extrusion. The measurements of the center of the sacrificed chambers were also consistent with our average results.

For the LCLS-II upgrade, two slightly different variations of chambers were required: one version for the soft x-ray (SXR) undulator line (Fig. 5) and one for the hard x-ray (HXR) undulator line (Fig. 6). The HXR chambers are mounted and aligned in a vertical orientation because the HXR undulators are horizontal-gap, vertically-polarized undulators.

ISBN: 978-3-95450-210-3 doi:10.18429/JACoW-FEL2019-THP068

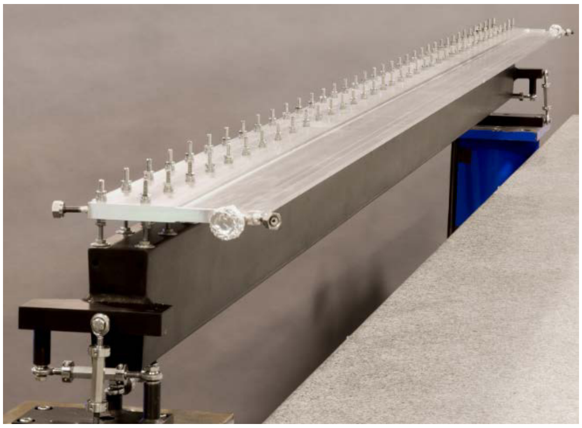

Figure 5: SXR chamber on alignment beam before installation of Earth-field coils.

Figure 6: Five HXR chambers assembled in alignment fixtures with water fittings and Earth-field coils.

Among the many requirements were that all chambers would maintain a finished nominal wall thickness of 0.5 mm, achieve a vacuum of less than 1×10^{-6} Torr, and a maximum outgassing rate after bake-out of less than 2×10^{-10} Torr*L/sec/cm^2. Chambers for both undulator lines are capable of being aligned to within ±100 µm straightness along their entire length. For this upgrade, all chambers are water cooled so that an operating temperature of 20°C, ±1°C can be maintained. All chambers have coils installed within the surface of the chamber to allow correcting for the Earth's magnetic field (without violating the space constraints; that is, the chamber thickness may not exceed 6 mm +0.15/ 0.05mm).

Sixty-four chambers (26 SXR chambers and 38 HXR chambers) and their alignment systems were delivered to SLAC for the LCLS-II upgrade.

REFERENCES

[1] G. Pile *et al.*, "Design and construction of the Linac Coherent Light Source (LCLS) undulator system," in *Proc. FEL'08*, Gyeongju, Korea, Aug. 2008, paper THAAU01, pp. 460-466.

[2] E. Trakhtenberg, P. Den Hartog, M. Erdmann, and G. Wiemerslage, "LCLS extruded aluminum vacuum chamber – new approaches," in *Proc. MEDSI 2008*, Saskatoon, Canada, 2008.

[3] H.-D. Nuhn, "LCLS-II undulator vacuum chamber surface roughness evaluation," LCLS-II, LCLSII-TN-17-08, March 2017.