LCLS EXTRUDED ALUMINUM VACUUM CHAMBER – NEW APPROACHES*

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Abstract

The Linac Coherent Light Source (LCLS) will be the world's first x-ray free electron laser when it becomes operational in 2009. Synchrotron radiation will be produced by 33 undulators, each 3.4 meters long, with a fixed gap of 6.8 mm. Vacuum chambers for these undulators should have the maximum possible vertical aperture.

Multiple vacuum chambers for insertion devices with 1-mm wall thickness were developed at Argonne for the Advanced Photon Source and many other synchrotron radiation facilities [1]. Decreasing the vacuum chamber wall thickness down to 0.5 mm could help to achieve a vertical beam aperture of 5 mm while still having an overall chamber thickness of 6 mm within the undulator pole gap of 6.8 mm. Multiple tests with extrusions from different vendors showed that the chamber can be leak free even with a wall thickness of 0.4 mm [2]. Our collaboration with the extruding company allowed us to get an extremely high extrusion quality, aperture location stability with respect to the outside surface, and an improved initial aperture surface finish.

Due to an extremely short electron bunch length, one of the key requirements from the physics specification was to achieve the best possible surface finish within the chamber aperture. The highly polished aperture was achieved with the application of a standard industrial process, abrasive flow polishing, used in a novel way. Normally, the maximum aspect ration for this process is 8/1, depth to aperture. In this case the process was extended to enable polishing a small oval aperture (5 mm x 11 mm) of the 4-meter- long extrusion with an aspect ratio ~700/1 to meet the critical surface roughness finish defined by RF impedance requirements.

Precise machining of the 0.5 ± 0.05-mm wall thickness and the requirements for flatness within 50 microns over the 3.4m length required the development of special fixtures and technology to produce 40 of these chambers.

A special cleaning procedure after the abrasive flow polishing was developed to achieve minimal residual outgassing. Welding of the end bi-metal flanges, the baking procedure, and quality assurance tests to ensure proper chamber quality will be presented as well.Abstract text goes here, using 11pt italic font. The CLS will host the fifth international conference on Mechanical Engineering Design for Synchrotron radiation Instrumentation in Saskatoon, June 2008. MEDSI 2008 will present the state of the art and outlook for innovative design as well as technology under development in existing and new generation light sources.

The Linac Coherent Light Source (LCLS) extruded vacuum chamber is a transport pipe for an electron beam and its induced synchrotron radiation. Physics specifications required a vertical beam aperture of nominally 5 mm with a maximum allowable overall chamber height of 6 mm thus a very thin 0.5 mm wall. The internal surface finish requirement was between 200-150 nm (RMS) along the extrusion direction to minimize interactions with the particle beam. Taking into account that the pole gap for the

LCLS undulator is 6.8 mm, the chamber external surface should be machined to a flatness better then 50 microns along the entire chamber length of 3.4 meters.

The major challenges to produce an extruded vacuum chamber meeting these requirements were:

1. One has to be positive that an extrusion machined to a wall thickness 0.5 mm or even slightly less (due to manufacturing tolerances), will be vacuum tight.
2. From previous experience, the aperture surface finish inside the extrusion would be 800-1000 nm along the extrusion direction. It was necessary to find a way to improve surface the finish dramatically.
3. Wall thickness tolerance and vacuum chamber flatness has to be much better than previously achieved.

Vacuum integrity of the thin wall was the most critical item and was studied at the beginning of 2007 [2]. The first experiments used the extrusion for the vacuum chamber for the TESLA Test Facility. The wall initially was machined to 0.6 mm. Wall thickness was measured mechanically during machining and also ultrasonically. Results of the measurements were very consistent. The wall thickness then was decreased in two steps to 0.5 and 0.4 mm. The vacuum inside the first samples with a 0.4 mm wall thickness was 5.6•10-5 Torr and 2.7•10-5 Torr (samples were not baked). After baking, vacuum was improved to 1.4•10-7 Torr. For all tests, an Alcatel-ASM 180 leak detector was used. No leaks, nor wall deflection were detected during these tests.

The same types of tests were performed for the actual LCLS vacuum chamber probe extrusion. The wall thickness was machined initially to 0.6 mm, then to 0.5 mm and then to 0.4mm. Vacuum before baking was 2.1•10-7 Torr during the 0.6 mm test, 1.7•10-7 Torr during the 0.5 mm test and 1.3•10-7 Torr for the 0.4 mm test. No leaks were detected in any test. The tests also showed no detectable deflection of the thin wall, which was consistent with the preliminary calculations.

It is important to note that the extrusion for the TESLA chamber was made by "Taber Metals" and the extrusion for the LCLS chamber was made by the different vendor - "Cardinal Aluminum Co." This lends credibility to the fact that regardless of the vendor, the extrusion process yields chambers that can be machined to a thin wall without any leaks even after baking.

During the preparation for the extrusion process we tried, together with our vendor - "Cardinal Aluminum Co.", to improve the surface finish inside an extrusion. The inner part of the die (mandrel) was made interchangeable and we brought one of the mandrels to Argonne to polish its surface at the APS optical shop. A surface finish inside the aperture close to 700 nm along the extrusion direction was achieved, but the further improvements were still necessary.

The highly polished aperture was achieved with the application of a standard industrial process, abrasive flow polishing, used in a novel way.[3] Normally, the maximum aspect ration for this process is 8/1, depth to aperture. In this development the process was extended to enable polishing of a small oval aperture (5 mm x 11 mm) of the 4 meter long extrusion with an aspect ratio ~700/1 in order to meet the critical surface roughness finish defined by RF impedance requirements. Another benefit of the process is that such a surface finish reduces the residual outgassing and improves the vacuum inside the chamber. This is very important for a chamber with practically zero conductance along the 3.4 meter length since pumps are located only between undulators in the break sections.

Over several months the technology of this polishing was developed. It was performed on the extrusion from both ends using different abrasive grits. Aluminum oxide was chosen as the abrasive material to prevent surface contamination. Polishing was performed while the chamber temperature was ~90 F to decrease the viscosity of the polishing media. A special fixture was designed to connect quickly and easily reconnect the extrusions to the press with the media barrel through an adapting vessel. The average polishing time was 50 hours per extrusion. Each author should submit all source files (text and figures), and a hard copy version of the paper. This will allow the editors to reconstruct the paper in case of processing difficulties and compare the version produced for publication with the hard copy.

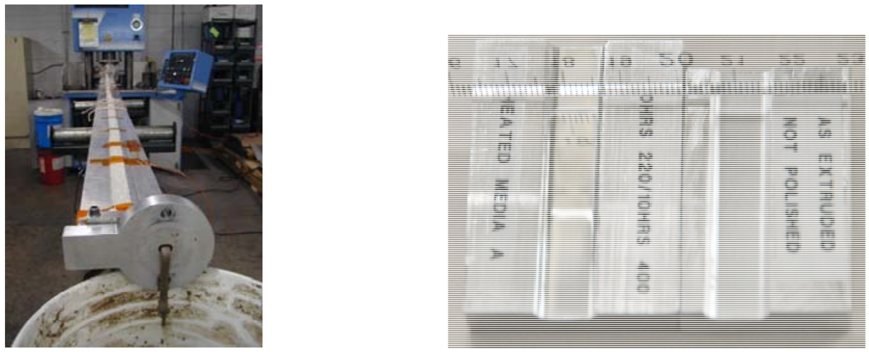


Fig 1 - Abrasive flow polishing process and samples before and after polishing

The manufacturing process for these chambers consisted of three steps that broke new ground: The extrusion process with the tolerances and internal surface finish far above the standard requirements, the abrasive flow polishing process, and the milling process that achieved a new cutting precision of the chamber thickness and wall thickness over a 3.4 meter long vacuum chamber.

a b c

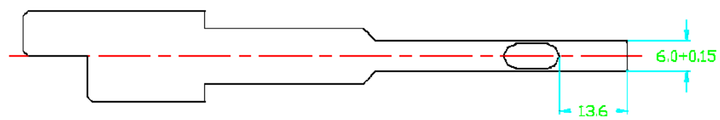
Fig 2: a – extrusion section; b – machined chamber cross-section; c - welded vacuum chamber prepared for cleaning.

Abrasive flow polishing was performed before machining. The main reason for that is the pressure at the media entrance end is about 430 PSI, and it would deform the thin 0.5 mm wall that exists after machining. Each extrusion was made longer (4 meter) than the actual chamber (~3.4 meter long) in order to have extra material from both ends for sampling to check the polishing quality. The Metrology Laboratory at APS did all the surface finish measurements and calculated the slope error at two spots on each sample along and across extrusion direction. The desirable specification parameters were <15 mrad in the extrusion direction and <60 mrad transverse. Our average results after measuring all chambers were 14.86 mrad and 35.14 mrad, respectively. Five extrusions were cut to verify the surface finish in the center of the extrusion—those measurements were also consistent with our average results.
To get the best milling tolerance each extrusion was straightened before machining to a flatness of ±50μ. A portable hydraulic press with a 10 ton capacity was used for this operation. A precisely ground 4 m long square bar was prepared to mill the extrusion. The extrusions were clamped to the bar in such a way as to allow machining both chamber sides from one set up. The chambers were machined step by step with the constant control of the wall thickness using an ultrasonic gauge. Inspection showed the outside thickness of all chambers was within 50 μm, while wall thickness dimensions were within ±25 μm.
One of the challenges connected with abrasive flow polishing was how to successfully clean the chamber and remove all residual substances from the aperture without damaging the surface quality. Proper cleaning procedures were developed –first each chamber was flushed through with hot Citronox solution, then 50% ultrasonic power were applied for 20 minutes inside Citronox bath with consequent DI water rinsing and hot nitrogen drying. RGA scans showed no mass peaks above 44. Although the

specified vacuum range was <10-7 Torr, we were able to achieve vacuum of 10-8 - 10-9 Torr after baking.

End flanges for the LCLS vacuum chambers were EVAC–type due to a very limited space in the break sections. All chambers were manually welded using a standard bi-metal combination (316 St. steel + 2219 Al. Alloy) provided by Atlas Technology. Each flange was fully inspected before welding and sealed to a blank EVAC flange using a standard gasket. There were zero leaks making 82 welding joints.

Inspection of the LCLS vacuum chamber included visual inspection and dimensional inspection, which was primarily chamber flatness, wall thickness, and chamber length after welding. Each chamber was tested by aligning to the required tolerance before baking in the horizontal plane on the standard LCLS support stand with the standard adjusters. After production of the first 6 chambers we changed the chamber cross-section design to reduce the influence of roll during alignment.



First six chambers

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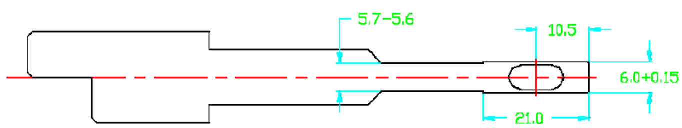

All other chambers

Fig 3 – Changes in the LCLS vacuum chamber design

After implementation of these changes alignment time decreased from two days to 4 hours. Each chamber was baked at the temperature of 150° C for 48 hours. For each chamber an RGA scan was done and residual outgassing was determined. Before shipment each chamber was filled with dry nitrogen and sealed from both sides, with one side equipped with a small valve.

Conclusion

Below is the list of the technological challenges which we were able together with our vendors to overcome:

- High-quality long and precise extrusion **("Cardinal Aluminum").**
- Stretching of an extrusion to eliminate major waviness and twist **("Cardinal Aluminum").**
- Abrasive flow polishing of the chamber aperture to achieve a mirror finishes for the 4 meter long extrusion **("Engineered Finishing Co").**
- Additional straightening of the extrusion within ± 0.05 mm over 4 m length **("Hi-Tech Mfg.").**
- Precise machining to the specifications **("Hi-Tech Mfg.").**
- Vacuum-tight bimetal end components **("Atlas Technologies").**

- Special ultra high vacuum cleaning procedure after abrasive flow polishing while keeping aperture surface intact **(in house).**
- TIG hand welding with no underbead **(in house).**
- Baking and vacuum certification **(in house).**

41 chambers were produced and shipped to SLAC on schedule and within the allocated budget.

Fig 4 – Last LCLS vacuum chamber are ready for shipment to SLAC

References

[1] E.Trakhtenberg, G. Wiemerslage, P Den Hartog, "New Insertion Device Vacuum Chambers at the Advanced Photon Source," PAC 2003 Particle Accelerator Physics Conference; Portland, OR, May 2003, 830 (2003).

[2] Emil Trakhtenberg, Greg Wiemerslage "A Study of the Minimum Wall Thickness for an Extruded Aluminum Vacuum Chamber," PAC2007, Albuquerque, New Mexico, June 2007, 1151 (2007).

[3] Ray Dargis. "Non-Traditional' Goes Mainstream." http://www.pfonline.com/articles/020802.html

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