EXTRUDED ALUMINUM VACUUM CHAMBERS FOR INSERTION DEVICES*

Emil Trakhtenberg, Patric Den Hartog, Greg Wiemerslage
Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439, USA

Abstract

Extruded aluminum vacuum chambers are commonly used in the storage rings of synchrotron facilities. For 18 years the APS has designed and fabricated vacuum chambers made from extruded aluminum for use with insertion devices at the APS and for use at other facilities including BESSY II, the Swiss Light Source (SLS), the Canadian Light Source (CLS), the TESLA Test Facility (TTF), and the European Synchrotron Radiation Facility (ESRF). Most recently extruded aluminum chambers were developed for LCLS with a 0.5-mm wall thickness along the entire 3.8-meter length. Surface roughness for the LCLS vacuum chamber interior was reduced, on average, to less than 300 nm through an abrasive flow polishing technique. Currently under development is an extruded aluminum chamber for the superconducting undulator at the APS. So far, 120 vacuum chambers have been produced with these methods. Results of the development, construction, and manufacturing of extruded aluminum vacuum chambers with small vertical apertures and thin walls are presented. The design, technological challenges, and positive and negative experiences are discussed.

INTRODUCTION

There is a general need within the synchrotron radiation community to have insertion devices with pole gaps as small as possible. We know three ways in which to achieve this goal: use in-vacuum undulators and wigglers without a separate vacuum chamber (VC); use a small-aperture stainless steel vacuum chamber—usually with non-evaporate getter NEG coating for pumping; or use a small-aperture extruded aluminum vacuum chamber with a thin wall. In-vacuum insertion devices can achieve as small a gap as desired, but they are quite expensive to manufacture. In addition, removing such a device from a storage ring is impossible without breaking vacuum and shutting the entire storage ring down. Stainless steel vacuum chambers are relatively inexpensive to fabricate but may have measureable and non-uniform permeability areas around the welds—even when made of 316L SS. That can compromise insertion device tuning, especially for chambers with welds in the vicinity of the magnetic field.

Extruded aluminum insertion device vacuum chambers (IDVCs) are definitely non-magnetic and, when they are fabricated with very thin walls, IDs using IDVCs can achieve nearly as small a gap as in-vacuum undulators but without incurring the high cost and maintenance difficulties [1].

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THIN-WALL EXTRUDED ALUMINUM VACUUM CHAMBERS FOR APS

There are 32 extruded aluminum IDVCs installed at the APS storage ring with apertures of 5 mm, 7.5 mm, and 8 mm; a nominal length of 5 m; and a 1-mm wall thickness for chambers with an elliptical aperture, and 1.25-mm for chambers with an oval aperture (see Fig. 1).

Figure 1: The latest thin-wall extruded aluminum vacuum chamber for APS

Besides APS, we have designed and delivered 16 VC to BESSY-I, four to SLS, two to CLS, and one to ESRF with cross sections that are more or less similar to the APS design. We have designed and delivered 14 flat vacuum chambers with a 9-mm round aperture and 11-mm outside vertical dimension to DESY.

In 14 years of work with this type of chamber we have proven the following:

1. We may produce extruded Al IDVC with vacuum-tight walls with thicknesses 1±0.1 mm after machining.
2. It is routinely possible to make ~5-m-long VCs with flatness better then ±75 μ along the whole length after chamber installation on three supports. This allows us to have a minimum undulator pole gap of 10.5 mm for an IDVC with a nominal 10-mm outside dimension.
3. It is routinely possible to get certification pressure inside a ID-VC of better than 2×10^{-10} Torr.
4. We were able to produce an ID-VC with a 5-mm vertical aperture (extreme case).
5. Deflection of the thin wall in the center of an aperture is less than 100 μ for all VC cross sections.

EXTRUDED SUPER-THIN-WALL VACUUM CHAMBERS FOR LCLS

The Linac Coherent Light Source (LCLS) extruded vacuum chamber is a transport pipe for an electron beam and its induced synchrotron radiation (see Fig. 2). Physics specifications required a vertical beam aperture of nominally 5 mm with a maximum allowable overall chamber height of just 6 mm, thereby requiring a very thin 0.5-mm wall. The internal surface finish requirement was between 150-200 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 of better than 50 microns along the entire chamber length of 3.4 meters. 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 was then 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. No leaks or 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 0.4 mm. 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 of these tests. The tests also showed no detectable deflection of the thin wall, which was consistent with the preliminary calculations.

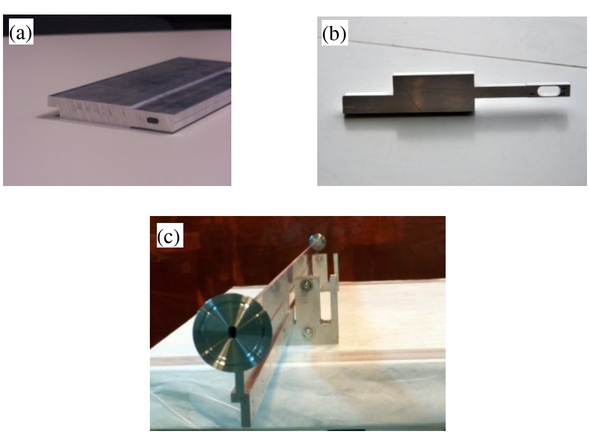

Figure 2: (a) Extrusion section; (b) machined chamber cross-section; (c) welded vacuum chamber prepared for cleaning.

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 a 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.

The highly polished aperture was achieved with the application of a standard industrial process, abrasive flow polishing (see Fig. 3), used in a novel new way [3].

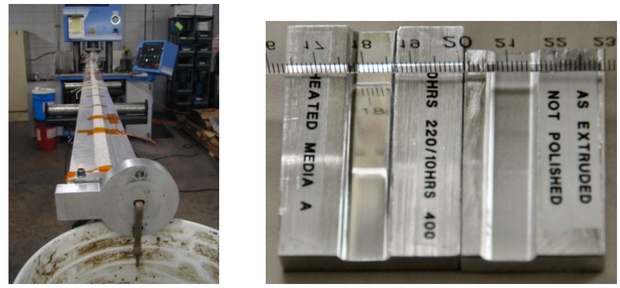

Figure 3: Abrasive flow polishing process and samples before and after polishing

Normally, the maximum aspect ratio 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 × 11 mm) of the 4-m-long extrusion with an aspect ratio of ~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 conductivity along its 3.4-m length since pumps are located only between undulators in the break sections.

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 the 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. Forty vacuum chambers for the LCLS were produced, inspected, certified, and shipped to SLAC in a less than a year.

EXTRUDED VACUUM CHAMBER FOR THE SUPERCONDUCTING UNDULATOR

A planar superconducting undulator (SCU) is currently under development at APS and an extruded vacuum chamber for this device is shown on Fig. 4.

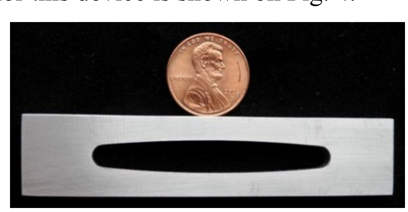

Figure 4: SCU vacuum chamber extrusion cross section.

This vacuum chamber has quite a wide horizontal opening (53 mm) to allow synchrotron radiation from the upstream bending magnet to pass through. The chamber is located inside a cryostat and will have an operating temperature of 20K°. That is why it has no distributed pumping. Standard end boxes with a lumped NEG pump and an ion pump will be located at both ends of the straight section, where the SCU cryostat will be installed. The row extrusion is three meters long and has 5.5-mm walls; these are enough to form welding profiles at the ends to join with bi-metal flanges similar to what we designed for the LCLS chambers. Actual chamber wall thicknesses after machining will be nominally 0.75 mm. In the normal mode of operation vacuum will be both inside and outside of the vacuum chamber, but we have calculated deflection of the chamber walls in case of a catastrophic helium leak inside the cryostat when pressure could achieve 1.5 Atm. Even in this case, maximum wall deflection will be 0.15 mm. Initially we are going to build two to three such devices, but the minimum order is 12 extrusions. Nevertheless the price for all these extrusions, including die development and production run, is still below $10K.

We have a very tough space constraint for this chamber with a vertical aperture of 7.2 mm and tolerance for the vertical aperture of just ±100 µm. In the extrusions they produced (we have measured three samples from the different extrusions) the actual tolerance of the vertical aperture was ±10 µm. The ability of our vendor Cardinal Aluminum to produce such a precise extrusion is remarkable.

CONCLUSION

Extruded aluminum insertion device vacuum chambers are non-magnetic and can be machined to extremely thin walls. In addition, IDs using these chambers can achieve nearly as small a gap as in-vacuum undulators but without incurring the high cost or maintenance difficulties. A complete cycle of fabricating the thin-wall extruded aluminum IDVCs was developed and has been used for many years at the APS. Beyond production of the chamber itself, it also includes the manufacturing of bi-metal end flanges; high-quality end-flange welding with full penetration and no underbead; installation of beam position monitors with "Helicoflex" seals; and development of cleaning, baking, and certification procedures. Each step requires significant "know-how" and has no room for error. But with the proper personnel training and detailed preparation for each step, production of such chambers has become more or less routine.

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