ADVANCED PHOTON SOURCE EXPERIENCE WITH VACUUM CHAMBERS FOR INSERTION DEVICES

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Abstract

During the last five years, a new approach to the design and fabrication of extruded aluminum vacuum chambers for insertion devices was developed at the Advanced Photon Source (APS). With this approach, three different versions of the vacuum chamber, with vertical apertures of 12 mm, 8 mm, and 5 mm, were manufactured and tested. Twenty chambers were installed in the storage ring and successfully integrated into the APS vacuum system. All have operated with beam, and 16 have been coupled with insertion devices. Two different vacuum chambers with vertical apertures of 16 mm and 11 mm were developed for the BESSY-II storage ring and 3 of the 16 mm chambers were manufactured.

1 INTRODUCTION

A number of considerations in the design of undulators, such as a desire for high brilliance and a large tuning range, drive the design of the vacuum chamber to small gaps. On the other hand, particle beam transport considerations require the largest possible aperture. The competing requirements demand a vacuum chamber design with a minimum chamber wall thickness, close tolerances for straightness and flatness to enable precision alignment, and mechanical and thermal stability. Specialized insertion devices (IDs) often demand additional features in order to accommodate individual geometries.

Extruded chambers are economical for large accelerators such as the APS that can amortize the development costs over a large number of chambers. We have built a variety of long chambers, that have small vertical gaps, are straight and flat across the surface to within 50 µm, and that have performed well within the APS storage ring. The design depends on a rigid strongback that limits deflection of the chamber under vacuum despite a thin wall. All of these vacuum chambers have a wall thickness of 1.0 ± 0.1 mm at the beam orbit position, an elliptical beam chamber and a pumping antechamber with ST707 non-evaporable getter strips (NEG). Alignment of the vacuum chamber on its support is routinely accomplished with a precision of ± 75 µm over the entire surface, allowing minimum insertion-device pole gaps.

2 VACUUM CHAMBER TYPES

Versions of the vacuum chamber, with vertical apertures of 12 mm and 8 mm, and lengths of 2.5 meters and 5 meters were manufactured and tested [1]. Twenty aluminum chambers were installed in the storage ring and successfully integrated into the APS vacuum system. All but one have 8 mm vertical apertures (APS8). Of these, all are 5 m long and can accommodate two APS 2.4-meter long standard IDs. One 12-mm-aperture chamber is used with a 2.4-m-long wiggler (APS12). One stainless steel chamber has been built and installed for a specialized elliptical multipole wiggler (EMW)[2]. All have operated with beam, and 16 have been coupled with IDs, including the EMW. Additional chambers using the same approach but with 11 mm and 16 mm vertical apertures have been built for the BESSY II storage ring in Berlin (see Table 1).

	Vert. Aperture (mm)	Horiz. Aperture (mm)	Length (m)	Min. ID Gap (mm)
APS5	5	30	5.59	7.5
APS8	8	40	5.59	10.5
APS8	8	40	2.92	10.5
APS12	12	51	2.92	14.5
BESSY	11	45	4.53	13.5
BESSY	11	45	3.70	13.5
BESSY	16	60	4.53	18.5
EMW	19.6	66.6	3.10	23.0

Table: 1. Dimensions of ID vacuum chambers built at the APS. All are machined aluminum extrusions except the last, which is the EMW chamber described below.

2.1 APS8 and APS12 chambers

The chambers are fabricated by extruding 6063 T6 aluminum alloy to form a tube with the desired internal shape and machining the exterior to the final dimensions. The extrusion process must be tightly controlled in order to yield a chamber with the straightness and wall thickness uniformity that is needed. This is accomplished first by proper design of the die to maintain a balanced mass flow and by fine tuning the die through a series of test extrusions. Two or three die trials are usually necessary before the production run. The extruded tube is cut to length and stretched 5% while still warm and plastic to reduce warps and kinks.

As delivered, the extrusion is quite straight and uniform, with a variation of only ±0.150 mm over the entire length, but even greater straightness is required before machining in order to assure a constant thickness profile. The chamber is shimmed and straightened with a large bed hydraulic press and then the interior profile is probed to

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determine the axis of the ellipse that will serve as the reference for the final machining. The thickness of the chamber is repeatedly checked with an ultrasonic thickness monitor during the machining.

The chamber is inspected after machining and prepared for welding. Using an automatic welding machine, it is welded to 304 stainless steel boxes at each end with ports for vacuum diagnostics, an ion pump, and a 220 l/s NEG cartridge pump. The end boxes also accommodate rf transition sections and a photon absorber.

2.2 5-mm-aperture ID vacuum chamber

A 5-mm-aperture extrusion was designed and fabricated and successfully machined to the same exacting tolerances as the standard 8-mm-aperture chamber. The chamber end geometry was tapered to 12 mm aperture to enable use of the standard end box. The chamber was welded, assembled, certified for vacuum, and completely prepared for installation into the storage ring. This chamber can be used with the standard APS undulator down to a gap of 8.5 mm or possibly with a new ID with a shorter period down to 7.5 mm. The small fixed aperture places severe constraints on the beam orbit during injection. Current plans call for a test installation in the storage sometime during late 1997 or early 1998.

2.3 ID vacuum chambers for BESSY II

BESSY II is a synchrotron light source facility under construction in Berlin. The APS has collaborated with scientists and engineers from this facility to design and fabricate the ID vacuum chambers for a 1.7 GeV storage ring.

The chambers are similar to the APS standard chambers but without the internal NEG pumping and without the attached diagnostic end boxes. Two different vacuum chambers with vertical apertures of 16 mm and 11 mm were developed. Pumping is provided by 6 ion pumps attached to the back of the chamber through stainless steel Conflat flanges. These flanges and the SS end flanges are welded to the chamber through Al-SS bimetallic transitions. Three of the 16 mm chambers were manufactured, tested, and delivered to Berlin. The extrusions for the 11-mm-aperture chamber have been fabricated and machining has begun, with delivery scheduled for late 1997.

2.4 EMW Vacuum Chamber

The elliptical multipole wiggler (EMW) utilizes both a vertically oriented permanent magnetic field and a horizontally oriented electromagnetic field. The design incorporates a 3100-mm-long stainless steel vacuum chamber of rectangular cross section, with outer dimensions of 69 mm wide by 22 mm high and a wall thickness of 1.3 mm. The magnet structures completely surround the chamber on all four sides, positioned only 1 mm from the chamber when in use. This precludes use of an antechamber, as used in the standard ID vacuum chamber.

Given the constraints of the magnet geometry and the chamber length, two approaches were pursued for effective UHV performance. Both approaches utilize lumped NEG and ion pumping at either end of the chamber. One approach uses no additional pumping over the length of the chamber, relying on thorough cleaning and baking to minimize surface outgassing. The other method uses strips of sintered NEG material in diagonally opposed corners of the chamber top and bottom. The NEG material is activated by heating the chamber. Both approaches are complicated by the need to bake the vacuum chamber inside the EMW magnet structures. The system for *in situ* heating must maintain the temperature of the permanent magnet structures below 35 °C. Activation of the NEG strips requires heating the NEG material to at least 250 °C.

The heating system uses copper plates in contact with the outside of the vacuum chamber. A total of four plates are used, covering most of the chamber length on the top and bottom. A 1 kW heater is mounted to each copper plate. Reliable thermal contact is maintained with a number of clamps. Insulating boxes encapsulate the heating assembly. These boxes are made of thin stainless steel and filled with ceramic foam. The entire heating and insulating system can be installed within the EMW structure after the magnet assemblies have been retracted.

While an acceptable pressure for installation was achieved with the NEG-pumped chamber, it was not clear that the heat-activated NEG material provided a clear benefit. Heating the NEG material from the outside meant that the activated NEGs were subjected to heavy outgassing from the hot chamber, reducing their pumping speed and capacity upon cooling. Thus, the second test focused on the chamber without NEG pumping. The chamber was heated to 150 °C, the heaters were at 225 °C, and the outside of the insulating box reached a maximum of 61 °C. With ion pumping and activation of the other NEGs, a pressure of 1.7×10^{-10} torr was obtained, comparable to the level of the NEG-pumped chamber. This chamber was used for the EMW installation.

3 PERFORMANCE

3.1 Vacuum measurements

The ultimate pressure achievable during testing was 5.0×10^{-11} torr. Each chamber was certified at a pressure below 2.0×10^{-10} torr prior to installation. Initial installed pressure without beam is typically 1 to 5×10^{-10} torr. Photodesorption from synchrotron radiation raises the pressure to about 2×10^{-9} torr. After several weeks of beam conditioning, pressure with a beam declines to $< 1 \times 10^{-9}$ torr.

The ESRF observed [3] that dust particles of ferromagnetic material, possibly from the ST707 NEG strip, levitate into the beam aperture of the ID vacuum chamber during movement of the ID gap. The expected signature is a sudden drop in the lifetime of stored beam due to collisions with the levitated particles. No evidence of this effect has been observed at the APS.

3.2 Chamber heating

In order to be able to use the same style end box with various sized vacuum chambers, the transition necks down to a 12 mm ellipse. Each aluminum vacuum chamber is machined to provide a smooth transition from the chamber aperture to the 12 mm aperture of the end box. Consequently, a small fraction of bending magnet radiation can fall on the aluminum chamber if the beam is severely missteered in the vertical direction. The temperature has been monitored with thermocouples and heat sensitive tapes. Most chambers have never seen an increase beyond ambient temperature but a few have experienced transient rises to > 65 °C, the maximum limit of most of the installed tapes. In one case a higher range tape showed a temperature of 106 °C. No negative impact of this temperature rise has been observed or is expected.

3.3 Deflection measurements

Critical to the performance of the vacuum chambers is the rigidity and resistance to collapse under atmospheric pressure when evacuated. The width of the pumping slot between the beam chamber and the antechamber collapses about 100 µm, but this has a negligible influence on the conductance. Of more importance is the vertical aperture at the beam position (shown in figure 1). For the APS vacuum chambers, the 8 mm chamber has the largest deflection because the size of the pumping slot was chosen to be 6.35 mm to achieve the best conductance. Consequently, the area with the thin wall is rather extended. The BESSY chambers have greater deflections because the horizontal aperture is so large. The deflection is somewhat less for the 11 mm chamber. In addition, the 11 mm extrusion has been designed with a thicker root to reduce the collapse. During fiducialization prior to installation, the deflection is measured for each chamber in order to be able to precisely locate the center of the ellipse on the beam axis.

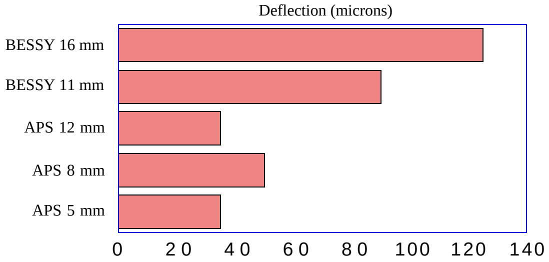

Figure: 1. Deflection of the center of the aperture of ID vacuum chambers under atmospheric pressure (per wall). The deflection of the 11 mm BESSY chamber is estimated.

3.4 Sealing vacuum leaks

A common feature of the ID vacuum chambers is the use of bonded aluminum and stainless steel in bimetallic transitions, which allow the joining of stainless steel and aluminum parts. A roll bond joint formed with a layer of 304 stainless steel alloy, a layer of pure aluminum, and a layer of 2219 aluminum alloy, provides a transition from the main chamber body to the stainless steel.

In the process of vacuum testing, several small vacuum leaks were discovered in the bonds. Sandwich plate was used for fifty-two standard end joints and for twenty-four circular ports. Of the fifty-two standard end joints, we have detected leaks in five. Of the twenty-four circular ports, leaks were detected in six.

To repair these leaks for an ultrahigh vacuum and a high radiation dose environment, a completely new method was tested using high velocity oxygen fuel (HVOF) metal powder spray deposition. An HVOF system accelerates a powder of the selected material to supersonic velocities. A variety of coating materials can be used including many metals and alloys, as well as ceramics. The high momentum of the particles creates a deposit with high adhesion, fine grain, and low porosity. The desired seal must introduce no contaminants into the system, particularly hydrocarbons, must seal after repeated bakeouts at 150 °C, and must be immune to radiation damage. To test the feasibility of the process, leak samples were prepared. One of the samples was sealed completely with a Cr_3C/NiCr coating.

The HVOF process is subject to a great number of variables including surface preparation, powder mixture, gas mixture and consumption rates, deposition rate, and substrate temperature. Each of the ID vacuum chambers was sprayed under different conditions with different results. Results vary from sealing the leak, to no change, to actually increasing the size of the leak (probably due to thermal effects). Given the proper set of conditions, however, it has been shown that it is possible to seal vacuum leaks for ultrahigh vacuum requirements. Further tests are planned to define the best parameters.

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REFERENCES

[1] E. Trakhtenberg, *et al*., The Vacuum System for Insertion Devices at the Advanced Photon Source, Proc. of the 1995 Particle Accelerator Conf., Dallas, TX, Apr 30 - May 5, 1995

[2] P. Den Hartog, *et al*., Design of the Vacuum System for the Elliptical Multipole Wiggler at the Advanced Photon Source, Proc. of Synchrotron Radiation Instrumentation Conference, Oct. 17-20, 1995, Argonne, IL

[3] N. Rouviere, ESRF Newsletter, No. 24, June 1995, pg. 15-16