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THE DESIGN OF THE ADVANCED PHOTON SOURCE UPGRADE (APS-U) SUPERCONDUCTING UNDULATOR (SCU) VACUUM SYSTEM*

M.E. Szubert†, E.R. Anliker, T.J. Bender, J.E. Lerch
Advanced Photon Source-Upgrade, Argonne National Laboratory, Lemont, IL, USA

Abstract

The Advanced Photon Source Upgrade (APS-U) includes four straight sections equipped with full length Superconducting Undulators (SCUs). These sections require vacuum systems that must span 5.383 meters at nominal length, accommodate the SCU device, and accommodate additional magnets for the canted configurations. In the direction of the beam, the upstream portion of the vacuum system is a copper chamber doubling as a photon absorber with a design that is manufactured to allow a 13.5 mm canting magnet gap. This portion of the vacuum system operates at room temperature and shadows the length of the vacuum chamber that operates within the cryostat at 20K. The vacuum chamber inside the cryostat is a weldment including a machined aluminum extrusion allowing for an 8mm magnetic gap, stainless steel thermal insulators, copper shields, and bellows/flange assembly. The vacuum system includes another room temperature copper chamber and absorber on the downstream end of the straight section. The vacuum system provides Ultra-high Vacuum (UHV) continuity through the straight section, connecting the storage ring vacuum systems.

INTRODUCTION

The APS-U project plan calls for the current APS 40 sector storage ring (SR) to be retrofitted with a new 6 GeV, 200 mA storage ring optimized for brightness above 4 keV. Superconducting Undulators (SCUs) equip 4 of the 40 sector straight sections which produce photons at various energies to Insertion Device (ID) beamline users based on their needs [1].

Each ID layout requires a vacuum system to ensure UHV continuity between SR vacuum systems. The SCU vacuum system interfaces with the SR vacuum systems at the up and downstream BPMs, and needs to span a nominal distance of 5.383 meters. At these locations, the SCU aperture matches the $\emptyset 22\,mm$ SR aperture. During operation, the vacuum system is fixed at the center of the straight section, and its length contracts 14 mm on each side; therefore, its operating length is 5.355 meters.

The straight sections equipped with SCUs accommodate two configurations, canted and inline. The sectors equipped with canted SCUs impose the most limitations for the vacuum system design. One vacuum system was designed to accommodate both canted and inline sectors. Having a uniform design aids in the production of these systems.

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† mszubert@anl.gov

OVERVIEW

The SCU Vacuum System consists of 3 assemblies: (1) upstream out-of-cryo vacuum assembly, (2) in-cryo vacuum assembly that resides inside the cryostat, and (3) downstream out-of-cryo vacuum assembly (Fig. 1). Within the straight section, the aperture varies between a 22 mm diameter round aperture, a 10.3 mm (H) x 49 mm (W) racetrack aperture, and a semi-elliptical aperture (Fig. 2). A transition feature is machined into both ends of the extrusion, blending the racetrack aperture and the internal extrusion geometry, and keeping any weld under-bead from impeding on the aperture. The smooth transitions are seamless to reduce beam impedance and occur in both the in-cryo and out-of-cryo systems.

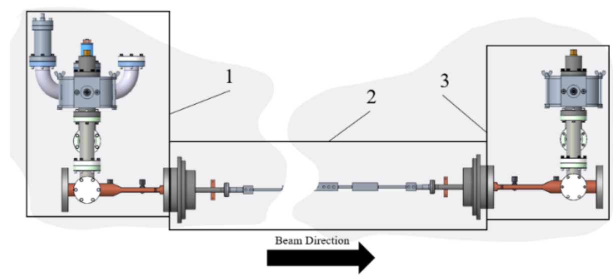

Figure 1: Vacuum sub-systems breakdown.

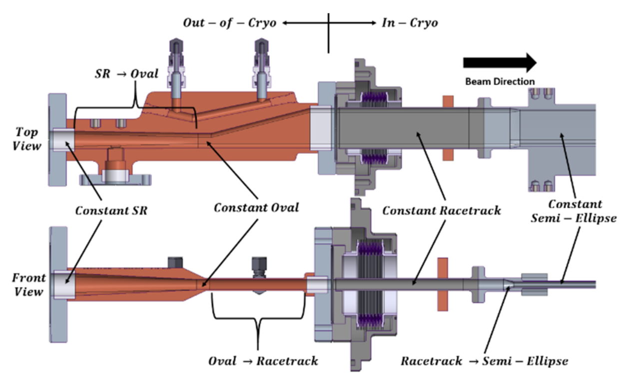

Figure 2: Aperture breakdown.

The aperture geometries are the result of the varying magnetic gaps and the requirement to prevent beam incidence on the in-cryo system. The out-of-cryo OF-Copper vacuum chambers act as photon absorbers; the upstream absorber protects the in-cryo vacuum system and the downstream absorber shadows 1.2 meters of downstream equipment.

The in-cryo chamber is supported as a part of the cold-mass inside the cryostat. The two out-of-cryo vacuum systems require supports external to the cryostat, using standoffs and threaded rods (Fig. 3).

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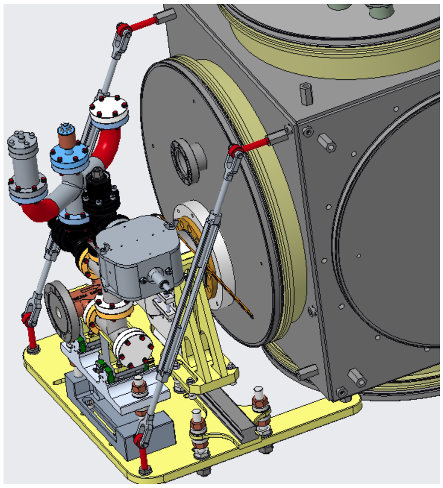

Figure 3: Support assembly.

IN-CRYO VACUUM SYSTEM

The in-cryo vacuum system describes the vacuum chamber weldment that resides inside the cryostat, spanning 4.8 meters. It is comprised of a machined aluminum extrusion (6063-T5), bi-metal components (SST/Al 2219), thermal insulators (SST) to minimize heat leak, thermal shield intercepts (copper) operating at 35K, and bellows assemblies (Fig. 4) accommodating thermal contraction.

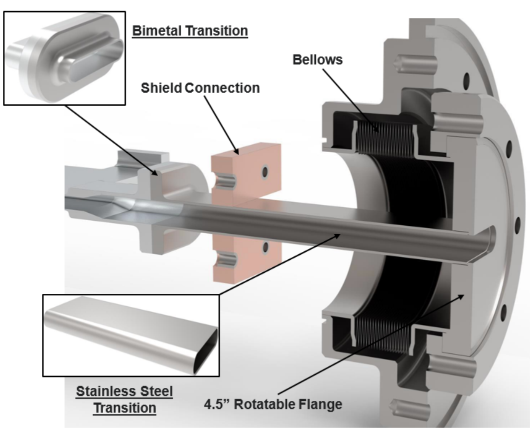

Figure 4: Weldment end.

The aluminum vacuum chamber makes up the majority of the weldment assembly length and is machined from a single 5 meter long extrusion (Fig. 5).

The aperture geometry is designed based on the following functional requirements: (1) the aperture height $\geq 6.0\ mm$, (2) the outboard aperture width must prevent radiation incidence, and (3) a minimum wall thickness of $400\ \mu m$ to accommodate the internal magnetic gap of 8 mm with adequate clearance. The resulting aperture and chamber wall thickness is shown in Fig. 6.

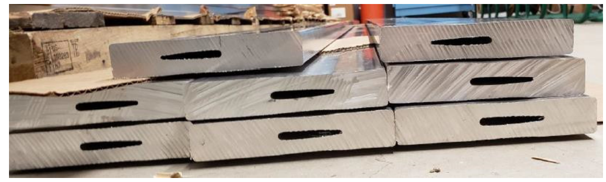

Figure 5: Extrusions received at Argonne.

Figure 6: Machined extrusion profile.

Test machining was completed on an extrusion with the same length (5 meters) but different aperture. In this case, the aperture was wider than the aperture developed for the APS-U SCU. This would make it harder to machine the wall thinner because the wall surrounding the aperture would deflect more while the cutting tool traversed the length of the extrusion. The testing achieved the $400\ \mu m$ wall thickness tolerance along its length, verifying the feasibility of fabrication and confirming the design.

The aluminum chamber is conductance-limited due to its length and small aperture, creating a challenge to comply with the necessary pressure requirements. The chamber was designed for cryo-pumping by maintaining an operating temperature of ~20K, based on sticking probabilities for various gases empirically derived at CERN. The weldment includes thermal insulators to minimize heat leak and braided copper links to thermally link the aluminum chamber to the 20K copper bus bar (Fig. 7). Ensuring the aluminum chamber maintains an operating temperature of 20K is a necessary condition to meet APS-U pressure requirements. The temperature of the chamber is also critical in maintaining the operational temperature for the magnets (4K) and preventing quenching. At the operating temperature, the chamber contracts ~14 mm per end, requiring a welded bellows/flange design on each end of the cryostat (see Fig. 4).

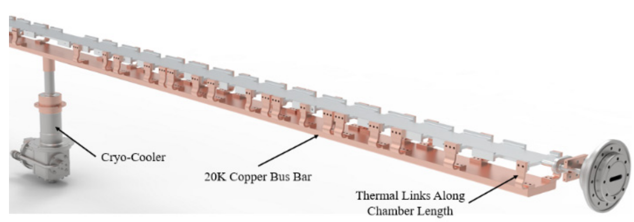

Figure 7: In-cryo weldment and thermal attachments.

OUT-OF-CRYO VACUUM SYSTEMS

Both out-of-cryo vacuum systems are copper chamber with integrated photon absorbers. They accommodate the heat load (based on the raytrace and summarized in Table 1) on the system from the upstream bending magnet, protecting the in-cryo system and 1.2 meters of downstream equipment.

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Table 1: Raytrace Results for Photon Absorbers

Component	Peak Power Density	Total Power
Upstream Absorber	$13\ ^{W}/_{mm^2}$	140 W
Downstream Absorber	$6\ ^{W}/_{mm^2}$	530 W

Water cooling channels, running parallel to the absorbing faces, and the high thermal conductivity of the copper are adequate to dissipate the heat load. (Fig. 8).

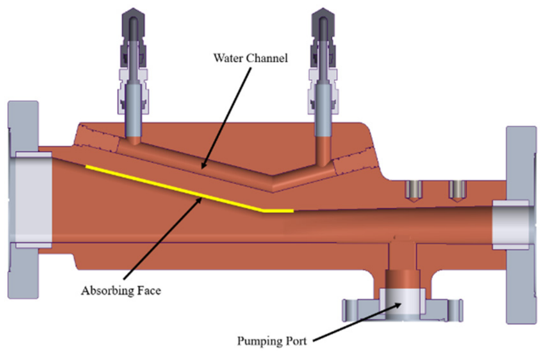

Figure 8: Downstream vacuum system cross section.

For both configurations, planed surfaces are required for alignment purposes. In addition, to accommodate canted configurations the minimum wall thickness is 1 mm in locations that interface with the magnet (Fig. 9).

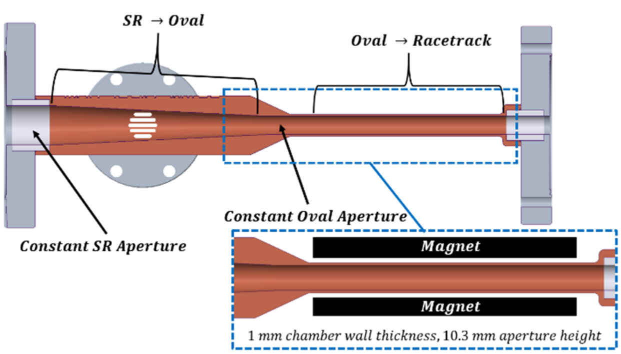

Figure 9: Upstream cross-section detail.

Internally, the chamber geometry includes two transitions. One blends the 22 mm diameter round storage ring aperture to an oval, 10.3 (H) x 18 (W), which creates the absorbing edge and prevents radiation to pass. The other allows the oval shape to transition to a 10.3 mm (H) x 49 mm (W) racetrack aperture, matching the inlet and outlet aperture shape of the in-cryo vacuum system.

OUT-OF-CRYO SYSTEM SUPPORTS

The out-of-cryo support system is suspended from various welded stand-offs on the APS-U SCU cryostat housing, mainly comprised of an aluminum support plate. The design must provide support for the vacuum chamber and vacuum equipment (Fig. 10, Item B), and canting magnet for sectors with canted configurations (Fig. 10, Item A). The support design is severely limited by space constraints and interfacing components. The individual supports allow the components to be manipulated in 6 DOF. The support plate allows for course and fine adjustment through use of turnbuckles (Figure 10, Item C) and fine-pitch threaded rods, respectively.

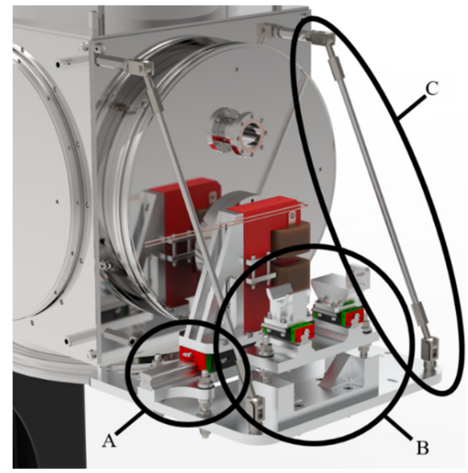

Figure 10: Out-of-cryo support assembly.

The vacuum chamber, canting magnet, and vacuum equipment are supported individually on top of the support plate. The design accommodates the mobility of the chamber, as it is affected by the in-cryo system undergoing thermal contraction. Mounted rails allow the necessary components to move naturally and, in the case of the chamber and vacuum equipment, in tandem. Assembly of the various slide rails requires procedural processes to ensure the natural movement can be maintained during operation.

CONCLUSIONS

A 5.383 meter long vacuum system is being developed for the full-length (4.8 meters) SCU for APS-U. The In-Cryo Vacuum Weldment is 4.8 meters long, allows for thermal contraction, and complies with the required sector pressures by operating at 20K and relying on cryo-pumping. The Out-of-Cryo Vacuum Chambers protect the extremely temperature-sensitive In-Cryo System and 1.2 meters of downstream equipment from the upstream bending magnets. The vacuum system accommodates both canted and inline configurations, incorporates seamless transitions among the various apertures, and provides UHV continuity between the other SR Vacuum Systems.

ACKNOWLEDGMENT

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REFERENCE

[1] APS-U *et al.*, "APS Upgrade Project Final Design Review Report," APS/Argonne National Laboratory, Rep. APSU-2.01-RPT-003, May 2019.