ISBN: 978-3-95450-229-5 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2020-MOPB11

THE ADVANCED PHOTON SOURCE UPGRADE (APSU) STRAIGHT SECTION VACUUM SYSTEMS FIRST ARTICLE FABRICATION*

M. Szubert†, E. Anliker, G. Avellar, J. Lerch
Argonne National Laboratory (ANL), Advanced Photon Source-Upgrade, Lemont, IL, USA

Abstract

The Advanced Photon Source Upgrade (APSU) includes 40 straight sections, 35 of which will be outfitted with Superconducting Undulators (SCUs) or Hybrid-Permanent Magnetic Undulators (HPMUs). The vacuum systems for these devices are primarily fabricated from aluminum extrusions and are required to provide Ultra-High Vacuum continuity between storage ring (SR) sectors for a nominal distance of ~5.4 meters. Each vacuum system has unique fabrication challenges, but all first article (FA) components have been produced successfully. The FAs arrived onsite at ANL installation-ready but have undergone functional testing activities to verify the production and vacuum certifications. The Insertion Device Vacuum Chamber (IDVC), used in HPMU sectors, is produced by SAES Rial Vacuum (Parma, Italy). The SCU vacuum system components are produced by two vendors, Cinel Instruments (Venice, Italy) and Anderson Dahlen (Ramsey, MN, USA). Based on the reliable outcomes and lessons learned from the FAs, production of the straight section vacuum systems is underway.

INTRODUCTION

The Advanced Photon Source Upgrade (APSU) 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 [1]. Thirty-five straight sections produce photons at various energies to the Insertion Device (ID) beamline users, with 31 straight sections equipped with Hybrid Permanent Magnet Undulators (HPMUs) and 4 straight sections equipped with Superconducting Undulators (SCUs).

Each of these ID straight sections require a vacuum system to ensure Ultra-High Vacuum continuity between SR sector arcs. They both interface with the P0 Beam Position Monitor Bellows assembly at the upstream (US) and downstream (DS) locations. At these locations, the vacuum systems match the Ø22 mm SR aperture, but transition to various shapes at their thin-wall locations. In addition, both vacuum systems accommodate two configurations, i.e. canted and inline. While the HPMU ID Vacuum Chamber (IDVC) and SCU Vacuum System designs differ based on their operational and interface requirements, each vacuum system has been independently optimized to achieve a uniform design for both the canted and inline variants in their respective sectors [2, 3].

* This research used resources of the Advanced Photon Source, a U.S. Department of Energy (DOE) Office of Science User Facility at Argonne National Laboratory and is based on research supported by the U.S. DOE Office of Science-Basic Energy Sciences, under Contract No. DE-AC02-06CH11357.
† Corresponding Author's Email: mszubert@anl.gov

OVERVIEW

Procuring the ID straight section components included long lead items, sole-source awards, and best-value vendor evaluation. Each purchase order introduced its own unique challenges, both due to technical capabilities and aggressive scheduling. The first articles (FAs) are necessary to prove the design concept and uncover issues that would avoid future production complications that may incur a cost increase or add schedule delays.

The designs require the use of complex manufacturing processes, modified vacuum procedures, complicated weld joints, and off-site testing by the vendors. The FAs for the straight section vacuum system are critical hold points in the production process for these new vacuum designs.

ID VACUUM SYSTEM

The fabrication of the ID Vacuum System consists of 3 aluminum extrusions, each modified to create a vacuum chamber (VC) with an integrated aperture transition, a strongback (SB) spanning the length of the straight section (~5.4 meters), and an additional support bracket to satisfy the aperture alignment requirements. After competitively bidding the fabrication of the IDVC and supports, the scope was awarded to SAES Rial Vacuum (SRV) in Parma, Italy. The aluminum components, extrusions and flanges, were supplied to SRV at the beginning of the project, with the remaining material, components, and equipment acquired by the vendor.

Fabrication of the FA included procuring the aluminum extrusions and aluminum flanges early in the design process as they were long lead items. Fig. 1 shows the extrusions at various stages of manufacturing: preliminary material removal of the VC (Fig. 1a), the trapezoidal SB with a mounting plate prepared for shipping (Fig. 1b), and the l-brackets that support the chamber 5 places along its length, allowing for alignment (Fig. 1c).

Figure 1: IDVC extrusion profiles throughout the fabrication process, 1a shows the VC, 1b shows a side view of the SB profile, and 1c shows the modified l-bracket profile.

Mech. Eng. Design of Synchrotron Radiat. Equip. and Instrum. MEDSI2020, Chicago, IL, USA JACoW Publishing
ISBN: 978-3-95450-229-5 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2020-MOPB11

The fabrication challenges included machining a thin wall feature (600 microns thick) for a length of 5+ meters, which allows for the IDs to operate at closed gap, integrating the aperture transition through conventional machining, and adhering to the AWS D17.1 weld specification [4].

Weld Development

The IDVC must operate for the lifetime of the APSU, or approximately 25 years. To ensure the success of these chambers, welds must adhere to class A or B welds, per AWS D17.1. While the design minimizes welds along the beam path, each weld is critical and most are thin wall connections, necessitating theoretically perfect welds with few-to-no porosities and inclusions. SRV worked to improve the weld quality, beginning with the weld sample deliverable, and continuing into the FA fabrication, including finding a vendor to perform the radiographic inspection. After radiographic inspection of the FA, many of the welds were class B but there were still non-conformities, with Class C welds present based on the tungsten inclusions and porosity size. The FA's intended use is for the installation mock-up, not for installation/operation, and therefore was acceptable, even with these discrepancies.

Re-evaluating the scope and deliverables, SRV agreed to produce a second article with installation-ready specifications, to be verified by x-ray inspection (Fig. 2). An additional weld sample was produced, and the process was vastly improved, producing all Class A or B welds. At the time of this publication, SRV has completed the 2nd article within specification and is confident in its welding capability. Production is underway [4]. APSU will randomly select 4 additional chambers to be x-ray inspected from the remaining 39 units, prior to shipment.

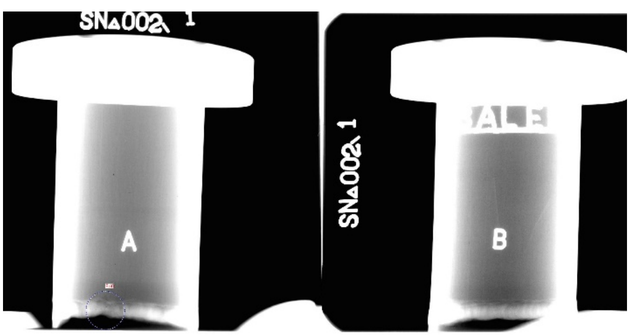

Figure 2: X-ray inspection of welds in the 2nd article, meeting Class A standard.

First Article Functional Testing

The scope of this award involved a thorough test plan for the FA. Due to COVID-19 international travel restrictions, the vendor performed the following tests for APSU remote approval of the FA: critical dimension verification, ultrasonic wall thickness measurement along the thin nose portion, vacuum certification producing a bake-out log and RGA scan, pumping slot deflection measurement, and aperture alignment [2, 4].

The vacuum certification is critical since the VCs will be stored under a nitrogen blanket for 2 years and need to be ready for installation during the dark time, beginning April 2023. While the vendor provides documentation for the proof of all these activities, the APS Mechanical Operations & Maintenance group verified the vacuum method by leak checking, pumping down, and baking out the chamber. (Fig. 3).

Figure 3: IDVC FA during bake-out at ANL.

Other components from this straight section vacuum system that have gone through similar test activities include: the photon absorber, ion pump, NEG cartridges, vacuum monitors, and installation cart. The IDVC fabrication and procurement process is estimated to be completed in December 2021.

SCU VACUUM SYSTEMS

The SCU Vacuum System consists of 3 assemblies: (1) US out-of-cryo vacuum assembly, (2) in-cryo vacuum assembly that resides inside the cryostat [5], and (3) DS out-of-cryo vacuum assembly (Fig. 4). 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 stand-offs and threaded rods.

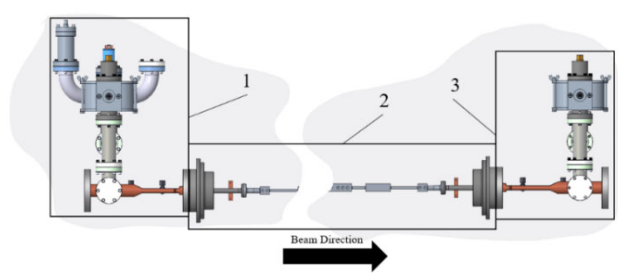

Figure 4: SCU VC assemblies, (1) US out-of-cryo VC, (2) in-cryo VC, and (3) DS out-of-cryo VC.

SCU In-Cryo Vacuum System

The FA in-cryo vacuum system has been produced by Anderson Dahlen (October 2020). This VC is a 4.8-meter long weldment spanning the length of the SCU cryostat. It is comprised of a machined aluminum extrusion, bi-metal joint, thermal insulation, and a flange/bellows assembly (Fig. 5).

The chamber's manufacturing challenges are the nominal wall thickness of 400 microns along the length of the extrusion, accommodating the small operating gap of the

SCU magnets, a brazing step for the chamber-end sub-assemblies, and the welding step of the aluminum from the bi-metal piece to the extrusion. Due to the specialized fabrication challenges, many vendors were vetted for their capabilities. Utilizing a domestic vendor was advantageous for oversight for the complex scope, although sample machining of the thin wall feature on a small length part was proven in past prototyping [3]. This resulted in the work being sole-sourced to Anderson Dahlen for the FA.

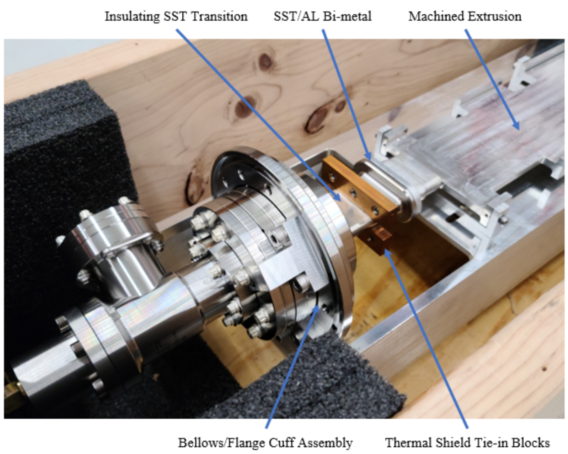

Figure 5: FA inline SCU VC weldment.

The FA fabrication was broken into three Purchase Orders for one vendor, (1) best effort machining of the thin wall of the extrusion, (2) brazing and welding the supplemental components at either end of the extrusion, and (3) welding the end sub-assemblies (copper blocks, stainless-steel (SST) insulator, and flange/bellows weldment). The FA weldment was completed in-spec and resulted in the remaining 3 weldments, with slightly modified geometry for the 2 canted chambers, to be awarded to Anderson Dahlen as well. While this is a significant amount of work for one vendor and leads to longer lead times, the quality and functionality of the end-product is the most critical factor.

SCU Out-of-Cryo Vacuum System

The FA out-of-cryo chambers have been produced by Cinel Instruments (June 2019) (Fig. 6). These are the smallest of the VCs in an ID straight section, but critical as they act as inline absorbers for synchrotron radiation, protecting the In-Cryo system and downstream equipment [3].

The vendor produced these components with minimal difficulty. The manufacturing process included preliminary machining of the copper, brazing SST collars to the copper, and welding SST flanges to these collars. Both US and DS require integrating a water-cooling channel to dissipate heat during operation. In addition to the vacuum processes previously discussed for the other systems, this feature required hydrostatic testing to 225 psi.

The scope of work also included producing the support assemblies that suspend from the cryostat and accommodate the VCs, vacuum equipment, and canting magnets (in canted configurations). The vendor delivered the FAs and production units fully assembled, ready for assembly to the cryostat [3].

Figure 6: DS VC undergoing inspection.

The fabrication processes for both the chambers and supports were straight forward and allowed the activities to remain on-schedule. The production units arrived at ANL in December of 2020. Even for simple components like these, the FAs allowed APSU to perform functional testing, resulting in support of the final design report analyses.

CONCLUSIONS

The APSU straight section vacuum systems have gone through the FA fabrication process, proving the validity of the designs, and allowing functional testing to be performed prior to full-scale production. Functional tests from each of the vendors, in addition to onsite testing, has resulted in confidence that the production units will arrive onsite, ready for installation.

ACKNOWLEDGMENT

This research used resources of the Advanced Photon Source, a U.S. Department of Energy (DOE) Office of Science User Facility at Argonne National Laboratory and is based on research supported by the U.S. DOE Office of Science-Basic Energy Sciences, under Contract No. DE-AC02-06CH11357.

REFERENCES

[1] APSU *et al.*, "APS Upgrade Project Final Design Review Report," APS, Illinois, United States, Rep. APSU-2.01-RPT-003, May 2019.

[2] J. Lerch *et al.*, "APSU upgrade insertion device vacuum chamber design", in *Proc. NAPAC2019*, Lansing, MI, USA, September 2019, pp. 450-452. `https://doi.org/10.18429/JACoW-NAPAC2019-TUPLS02`

[3] M. Szubert *et al.*, "The design of the Advanced Photon Source upgrade superconducting undulator vacuum systems", in *Proc. NAPAC2019*, Lansing, MI, USA, September 2019, pp. 453-455. `https://doi.org/10.18429/JACoW-NAPAC2019-TUPLS03`

[4] J. Lerch *et al.*, "Overcoming Challenges during the Insertion Device Straight Section Component Production and Tuning Phase of the Advanced Photon Source Upgrade", presented at the 11th Int. Conf. on Mechanical Engineering Design of Synchrotron Radiation Equipment and Instrumentation (MEDSI2020), Chicago, IL, USA, July 2021, paper MOOA01, this conference.

[5] E. Anliker *et al.*, "A new superconducting undulator cryostat for the APS upgrade", *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 755, p. 012126, 2020. `http://dx.doi.org/10.1088/1757-899X/755/1/012126`