ISBN: 978-3-95450-223-3 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2019-TUYBB3

FINAL DESIGN OF THE APS-UPGRADE STORAGE RING VACUUM SYSTEM*

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Abstract

The Advanced Photon Source Upgrade (APS-U) project is progressing from its final design phase into production for the future 6 GeV, 200 mA upgrade of the existing APS. The storage ring arc vacuum system will include over 2500 vacuum chambers made from a variety of custom designs ranging from 70 mm to 2.5 meters in length and typically feature a narrow 22 mm inner diameter aperture. The scope of NEG coatings was increased to 40% of the length along the e-beam path to ensure efficient conditioning and low pressure requirements can be met.

The final design phase required advancing previous work to a procurement-ready level and to address local and system level challenges. Local challenges include designing thin-walled vacuum chambers with carefully controlled lengths and outer profiles and also mitigating significant radiation heat loads absorbed along vacuum chamber walls. System level challenges include planning for the complex machine assembly, networking components to utilities, managing the quality of upcoming procurements. This presentation will highlight the major design challenges and solutions for the storage ring vacuum system and also plans for production and installation.

VACUUM SYSTEM REQUIREMENTS

APS-U will retrofit the existing 1.1 km circumference APS storage ring with a new 6 GeV, 200 mA multi-bend achromat storage ring. The new magnet lattice brings magnet poles closer to the electron beam and dictates a new storage ring vacuum system featuring thin-walled vacuum chambers with a nominal 22 mm ID circular aperture. Figure 1 compares the typical APS storage ring arc chamber profile to a typical new 22 mm ID APS-U chamber profile. The new profile represents about 40% of the length of each sector. Some chambers along the electron beam path feature antechambers as part of the pumping and photon extraction scheme but all these chambers feature a 22 mm inner diameter beam-side aperture.

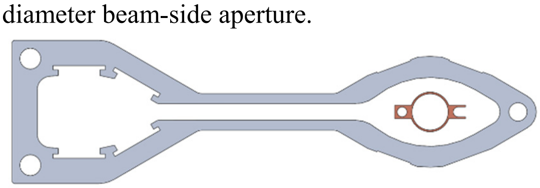

Figure 1: Cross section comparison of 318 mm wide APS chamber profile to 22 mm ID APS-U chamber profile.

APS consists of 40x sectors of a mostly uniform arc design with straight sections in between. This paper covers the scope of only the arc vacuum system design and not the straight sections. Each sector will be first built outside of the tunnel as five separate modules, each containing magnets, vacuum components, and supports. Modules will be connected by individual beam position monitors (BPMs) units featuring bellows on two sides. A project goal is to achieve the tunnel installation and accelerator and vacuum commissioning in no more than one year of dark time. The vacuum conditioning goal is to achieve good beam lifetimes at full 200 mA current by reaching 2 nTorr average pressures at full current by 1000 A*hrs of conditioning.

INTERFACES & DESIGN CHALLENGES

APS-U vacuum system chambers typically span narrow magnet pole gaps with ~26 mm inner diameter and are mounted to compact BPM units as shown in Fig. 2. A BPM design was developed with welded electrode feedthroughs and bellows on each end to accommodate thermal expansion. The BPM mounts to a rigid support base with thin support arms to mount and align the chambers while decoupling the BPMs from chamber vibrations. The integrated BPM, support, and vacuum-sealing chain clamp span fit within access gaps between magnets with minimum spans of 125 mm.

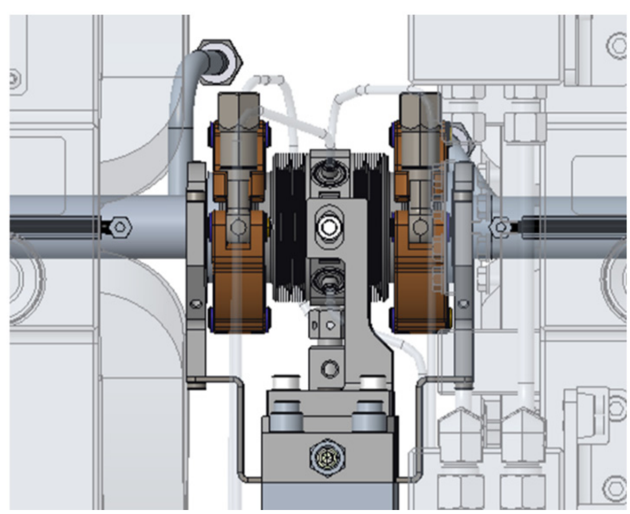

Figure 2: Central BPM support with extended supports for mounting and aligning neighboring vacuum chambers.

Uncooled components like the BPMs and flange gaps are shadowed by upstream components such as vacuum

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chambers and 'in-line' photon absorbers featuring machined reductions in aperture. Figure 3 highlights a typical APS-U vacuum sequence with upstream shadowing from a water-cooled copper absorber with a reduced aperture.

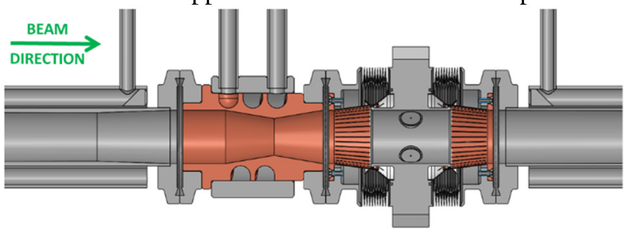

Figure 3: Typical APS-U vacuum sequence with an inline absorber shadowing a downstream BPM and flange joint.

VACUUM SYSTEM CAD MODELING

Each of the forty arcs of the storage ring vacuum system is comprised of 63 custom vacuum components including chambers, BPMs, and photon absorbers plus standard components such as ion pumps and gate valves. The assembly plan has been designed using a 'skeleton' based 3D CAD approach. Critical interfacing details such as the lengths of chambers and locations of joints are maintained in a top level skeleton. Simplified versions of chambers are created in referencing skeleton points. A simplified global assembly is created for a more efficient sharing of information across all levels of the machine. Detailed production models are then built referencing key features from the simplified model as detailed in Fig. 4.

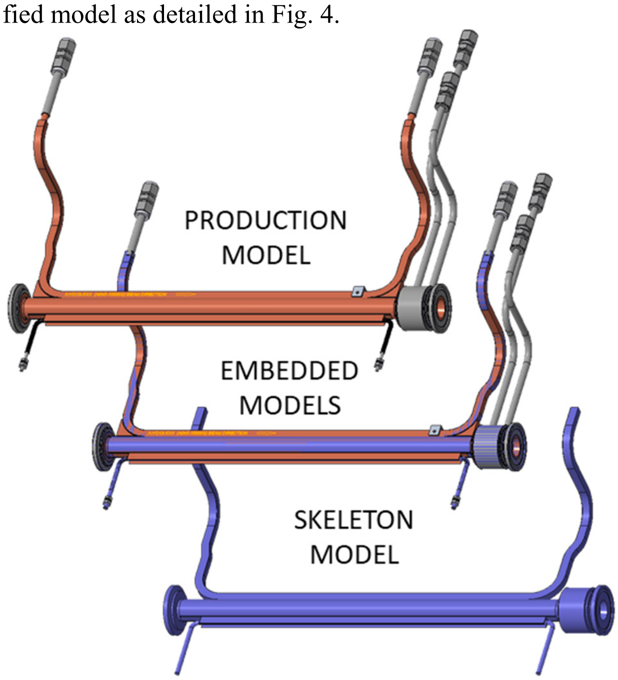

Figure 4: Simplified 'skeleton' models embedded within the designs of APS-U production models.

Figure 5 highlights ray tracing off of a crotch absorber. The ray trace model is built referencing simplified geometry allowing for subtle tweaks to apertures, careful tolerancing analysis, and quick rebuilding and analysis of the ray trace layout.

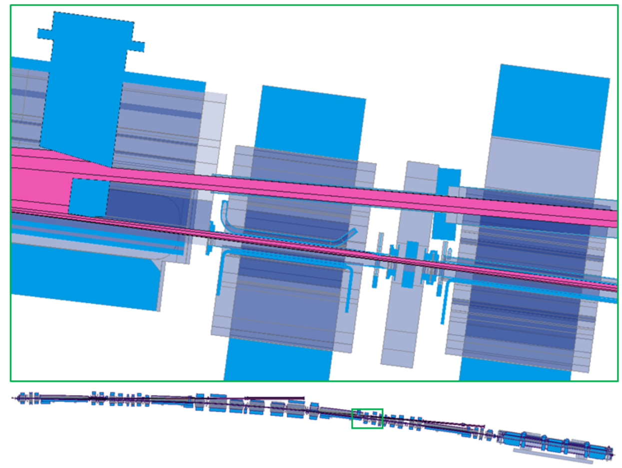

Figure 5: 3D CAD based ray trace created off skeleton assembly and highlighting ray trace off of a crotch absorber.

DESIGN OF VACUUM COMPONENTS

APS-U vacuum will consist of a variety of vacuum chamber shapes and materials [1] to meet the unique needs of the full length of each sector. 19 of the chambers per sector and 40% of the full storage ring length will be NEG coated. These chambers are typically tube-like, range from 0.3 to 1.7 meters in length, and are copper in high heat load zones, Inconel when passing through corrector magnets, and aluminium elsewhere. NEG-coated chambers will each feature an outboard water channel and are baked by an independent tube heater clamped to the inboard side of each chamber. 4 'L-bend' chambers are designed as bent aluminium extrusions with antechambers for NEG-strip pumping, and serve as the interface between e-beam chambers, extraction line chambers, and the mounting point for photon absorbers.

The photon absorbers consist of narrow CuCrZr bodies with precision-machined apertures and internal water cooling, see Fig. 6. The absorbers are typically mounted to outboard ports of L-bend vacuum chambers and feature a compact bellows to ensure precision alignment.

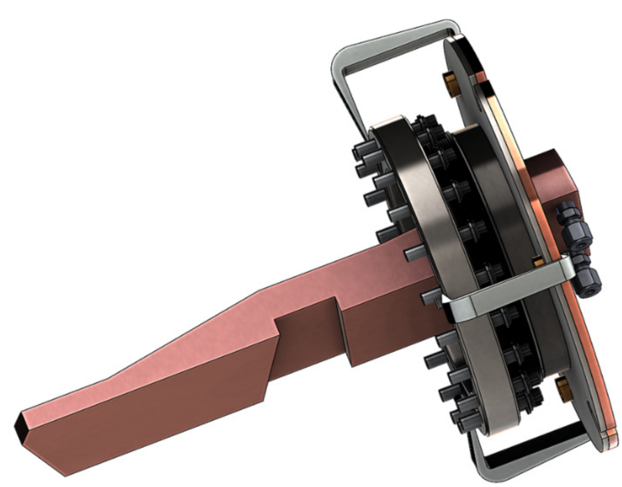

Figure 6: Typical APS-U photon absorber with bellows-based alignment.

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Each sector will include 14 BPMs. The standard BPM is a compact 70 mm length weldment, removable between narrow access gaps, and with welded bellows and electrode feedthroughs and detachable GlidCop RF fingers. Also included will be 2 specialty BPMs with extended outboard keyhole apertures as part of the photon extraction line.

A BPM prototype was recently fabricated and tested in the NSLS-II storage ring, see Fig. 7. The upstream RF fingers were not fully engaged due to unrestrained bellows motion. Beam was circulated but the fingers issue led to runaway heating at high beam currents, see Fig. 8. Follow-up tests with corrected RF fingers will occur at the APS in September 2019.

Figure 7: APS-U BPM with bellows prototype.

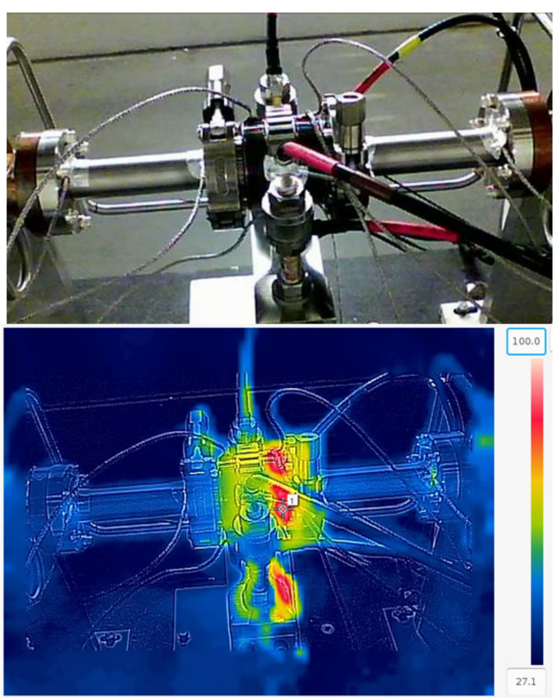

Figure 8: Setup and infrared image from August 2019 NSLS-II in-ring tests of an APS-U BPM prototype.

APS-U features a large quantity of flange joints, typically at connections to the removable BPM unit. RF seals are required for all joints along the e-beam path. The RF seal across each joint is created by crushing extended copper lips designed at the inner diameter of custom RF gaskets. RF gasket samples have been manufactured and tested to achieve both vacuum seals and RF seals as measured from APS-U's stretch wire Goubau line, see Fig. 9. Successful joints require a controlled torque spec on the single sealing bolt of the chain clamp.

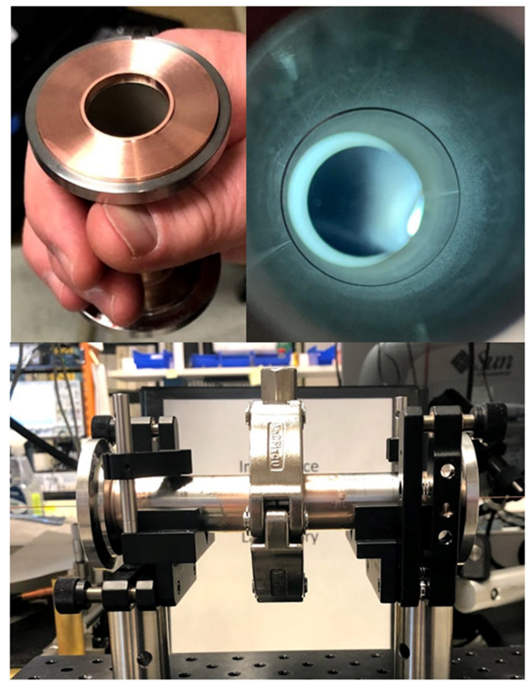

Figure 9: Single piece RF-sealing gasket (top left), inner chamber aperture with seal (top right), and standard joint evaluation on a Goubau line (bottom).

FUTURE WORK

APS-U Vacuum is now proceeding through the procurement and fabrication phases for all vacuum system components. The components will require extensive efforts in dimensional QA and vacuum certification. High level project goals include starting module installation of vacuum chambers, magnets, and plinth supports by Summer 2020 so that an in-ring installation can begin in 2022.

ACKNOWLEDGEMENTS

The Advanced Photon Source is a U.S. Department of Energy (DOE) Office of Science User Facility operated for the DOE Office of Science by Argonne National Laboratory under Contract No. DE-AC02-06CH11357.

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