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PROGRESS ON THE FINAL DESIGN OF THE APS-UPGRADE STORAGE RING VACUUM SYSTEM

J. Carter, B. Billett, B. Brajuskovic, M. Lale, A. McElderry, J. Noonan, M. O'Neill, K. Wakefield, D. Walters, G. Wiemerslage, J. Zientek, Argonne National Laboratory, Lemont, IL, USA

Abstract

The final design phase is underway for the APS-Upgrade project's storage ring vacuum system. Many aspects of the design are being worked on to address challenging interfaces and to optimize vacuum system performance. Examples of recent work include updates to ray tracing and vacuum analysis, new developments in vacuum chamber and photon absorber design, and further refinement of vacuum pumping plans to achieve the best possible pressure distributions. Recent R&D work and results from a vacuum system sector mockup have also informed designs and installation plans. An overview of progress in these areas and remaining challenges is presented.

APS-U VACUUM SYSTEM REQUIREMENTS

The APS-Upgrade will retrofit the existing 1.1 km circumference APS storage ring with a new 6 GeV, 200 mA storage ring optimized for brightness above 4 keV. The scope of the APS-U storage ring vacuum system design group includes the vacuum system and component design of 40 sector arcs as shown in Figure 1 and 5x specialty 'Zone F' straight sections. The goal is to install and commission the new ring with only one year of down time for the users and to condition vacuum to 2 nTorr average pressures at 200 mA beam current by 1000 A*hrs conditioning time.

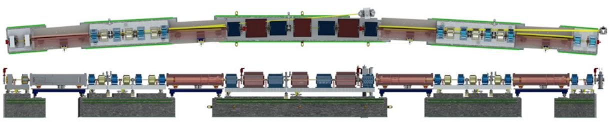

Figure 1: One 22 meter length sector of APS-U storage ring (excludes straight section).

The new storage ring design pushes magnet poles close to the electron beam and calls for narrow vacuum chambers, typically with a 22 mm inner diameter and 1 mm wall thickness. This is a substantial reduction from the previous APS design with an 84 mm wide x 42 mm tall elliptical aperture, see Figure 2 for comparison. A standard, 22 meter length arc of the vacuum system (not including straight sections) will include 27x custom vacuum chambers, 14x BPMs, 2x gate valves, 6x photon absorbers, 3x gauges, and photon extraction chambers. Of the 27x vacuum chambers, 19x will be round and NEG coated, 2x are keyhole, 2x vacuum crosses, and 4x are extruded aluminum 'L-bend' chambers. In total, 11.2 meters of the 22.1 meter length will be NEG coated.

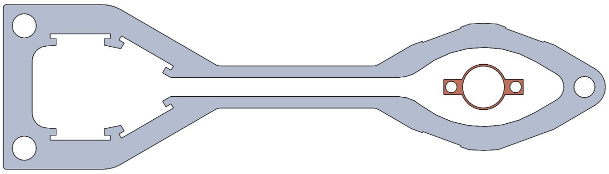

Figure 2: Cross section comparison of current APS-style vacuum chamber to new APS-U-style chamber.

INTERFACES

The APS-U vacuum systems are designed around careful interfaces with the needs of APS-U physics, magnets, and more. Vacuum components, flange seals, and absorbers must minimize impedance losses through the use of subtle transitions and reliable rf seals. The magnet's quantities, spacing, and narrow pole gaps drive thin walled vacuum chamber designs with narrow spaces to seal flanges and rout cooling water. Figure 3 demonstrates narrow installation and maintenance access between magnets to a compact BPM housing assembly. The vacuum system is also designed around numerous internal interfaces. Photon absorbers, both mounted and compact 'inline' style, are used to shadow and protect uncooled components such as BPM's, flange joints, and gate valves.

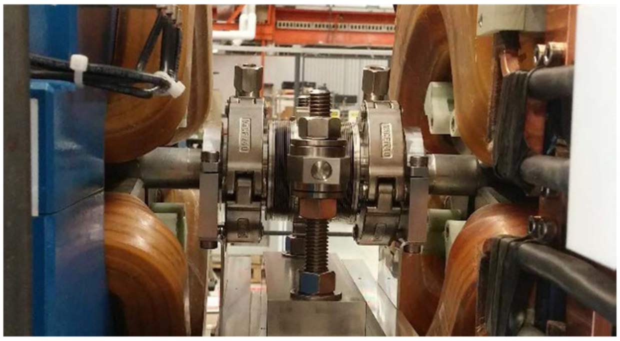

Figure 3: Narrow access between magnets to a compact BPM assembly demonstrated on a mockup.

VACUUM SYSTEM ANALYSIS

Ray tracing and vacuum analyses are performed using both 2D and 3D tools to understand and improve the limits of the vacuum system and to ensure design requirements are met. An analysis of vacuum pressures using programs like VACCALC for 2D models and MolFlow+ for 3D models helps predict the pressure profile through a hybrid pumping system. A standard arc pressure profile at 1000 A*hrs conditioning is shown in Figure 4. Pressures are typically low where distributed pumping is incorporated and high pressure bumps are found across conductance limited, small vacuum apertures. APS-U's vacuum analysis helped inform the decision to increase the preliminary design NEG coating scope from just the FODO section to now all round vacuum chambers. This is to reduce pressures across the arcs, build margin for developing straight section vacuum designs, and speed up vacuum system conditioning.

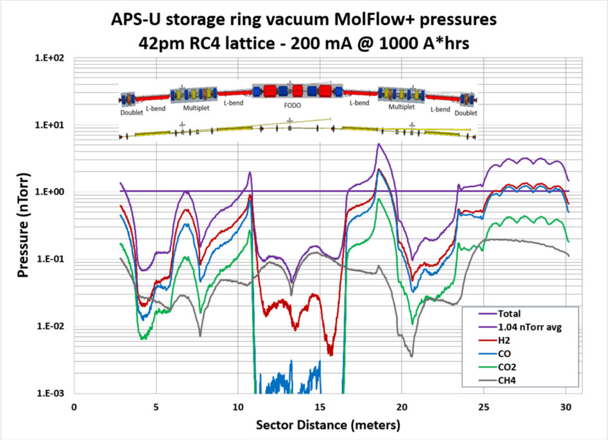

Figure 4: MolFlow+ analysis of standard arc vacuum system pressures at 200 mA, 1000 A*hrs conditioning.

Ray tracing reveals 'hot' zones in the vacuum system including the FODO section (1 kW/m) and B-Quad Doublet (700 W/m) where copper chambers are needed to absorb synchrotron loads. The B-side crotch absorber intercepts 3.4 kW, the most of six absorbers, with the A-side crotch next at 1.1 kW. Ray tracing is performed using 2D layouts and also new 3D tools which reveal missteering possibilities for conservative thermal analysis and have helped inform BPLD limits to protect narrow straight section chamber apertures.

VACUUM R&D

A major R&D activity for vacuum has been the construction of a mockup of one full standard arc of storage ring vacuum system components, see Figure 5. Manufacturing and assembly was completed in the Fall of 2017 and represent the vacuum system at the conceptual design level. Numerous tests are being informed on the mockup including pump down and NEG activation, validating vacuum gage readings to simulations, and water-flow induced vibration testing.

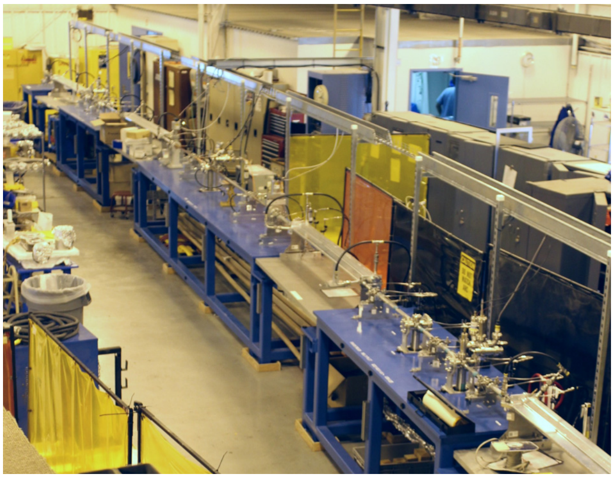

Figure 5: Full sector mockup of one standard arc of storage ring vacuum system components at conceptual design level, Fall 2017.

Water flow tests helped build confidence that turbulent flows can be used to cool irradiated vacuum chambers without transmitting significant vibrations through the bellows and onto BPMs. NEG activation tests helped build a recipe for activating NEG coated components in the presence of non-coated crosses and chambers. This also helped inform to remove 2x gate valves (of 4x total) originally designed to isolate the NEG coated FODO chambers. Remaining R&D activities include in-ring testing of new BPM button and housing designs.

FINAL DESIGN OF VACUUM COMPONENTS

APS-U's storage ring vacuum system is in its final design phase through early 2019. A standard arc's set of vacuum chambers will be manufactured from four separate common UHV materials and with respect to the total length per 22.1 m sector there will be 55% aluminium chambers (8 chambers, 12.1 m), 27% copper (7 chambers, 6.1 m), 9% Inconel (4 chambers, 2.0 m), and 9% 316 stainless steel (4 chambers + BPMs and Gate Valves, 2 m). Common chamber designs are compared in Figure 6. Aluminum chambers will include bent and extruded L-bend chambers with antechambers and also straight round tube-style chambers and integrated crosses. Copper chambers will be used when radiation loads across chamber walls are too hot for aluminum and are primarily round with some featuring slight bends. Stainless steel is used for keyhole and simple pumping crosses. Inconel will be used for tube chambers passing through 8-pole 'fast corrector' magnets where a low magnetic permeability is required.

Figure 6: Rendering of standard vacuum chamber designs (top) aluminum round chamber, (middle) aluminum vacuum cross, (bottom) copper round chamber.

Both the stability requirements for beam position monitors (BPMs) and their quantity, 14x per sector, dictate many of the challenges across the vacuum system design. APS-U BPMs must keep signal drift below 2 microns and vibrations less than 400 nm rms so a central housing with two bellows decouples the BPM button's from chamber motions. The quantity of both BPMs and magnets leads to narrow installation and maintenance access typically between 100-150 mm. The compact 74 mm length BPM design saves space on all parts of the length by using welded BPM buttons, compact bellows with +/- 5 mm travel, and Quick CF (QCF) flanges. The quantity of independent BPMs also drives the count of 44 flange joints per sector along the electron beam path.

APS-U requires that magnets should not need to be split during maintenance. This drives the decision to put rf-liners onto the removable BPM housing assembly and off of vacuum chambers whose relative simplicity should allow them to remain permanently between magnets. Figure 7 shows a cross section of the BPM assembly featuring an internal rf liner assembly which shields the bellows and includes a glidcop liner with fingers compressed by a stainless steel spring.

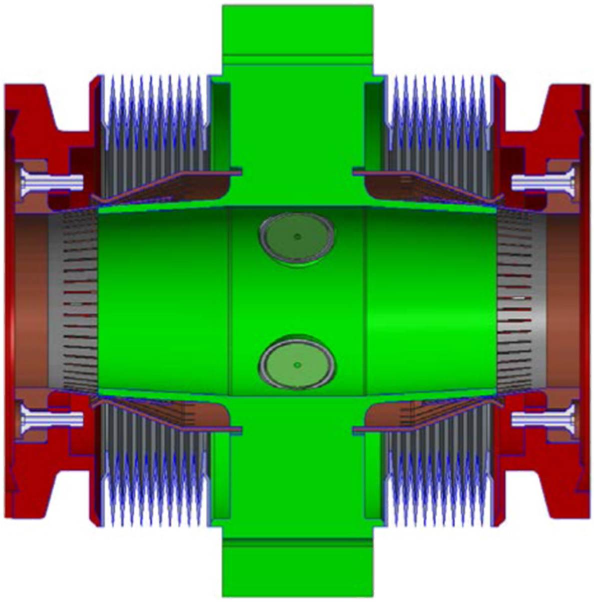

Figure 7: Cross section of compact BPM housing design with BPM buttons, GlidCop fingers, and two bellows all welded to a central stainless steel housing.

FUTURE WORK

APS-U vacuum will complete R&D by the end of 2018 and continue through final design of all vacuum components through early 2019. Some of the major design challenges ahead include two keyhole shaped BPM designs and developing and testing a robust, compact rf seal design for both round and keyhole flange joints. Manufacturing of production level components will run from 2019-2022. Pre-assembly of vacuum/magnet/support modules will happen from 2021-2022 followed by final assembly and installation in the tunnel and commissioning from 2022-2023.

ACKNOWLEDGMENT

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