RESEARCH AND DEVELOPMENT ON THE STORAGE RING VACUUM SYSTEM FOR THE APS UPGRADE PROJECT*

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Abstract

A number of research and development activities are underway at Argonne National Laboratory to build confidence in the designs for the storage ring vacuum system required for the Advanced Photon Source Upgrade project (APS-U) [1]. The predominant technical risks are: excessive residual gas pressures during operation, insufficient beam position monitor stability, excessive beam impedance, excessive heating by induced electrical surface currents, and insufficient operational reliability. Present efforts to mitigate these risks include: building and evaluating mock-up assemblies, performing mechanical testing of chamber weld joints, developing computational tools, investigating design alternatives, and performing electrical bench measurements. Status of these activities and some of what has been learned to date will be shared.

OVERVIEW OF THE SYSTEM DESIGN

A typical sector arc of the envisioned APS-U storage ring vacuum system is described in Figure 1. Each arc will be built of nine separable modules of four basic types which will be preassembled for rapid installation in the APS storage ring tunnel. Generally, the chambers are required to have a circular cross-section with 22 mm inner diameter and 1 mm wall thickness to fit inside of magnets. However, consideration of cost, performance, and required maintenance has led to a design by which the details of the chamber construction varies according to local spatial constraints and synchrotron radiation loading. The central "FODO" section, where intercepted bending magnet radiation is the greatest, will use tubular copper chambers with non-evaporable getter (NEG) coating and a single water channel on the outboard side. Chambers in the longitudinal gradient dipole, or "L-bend," sections will be built from bent aluminum extrusions which provide three water cooling channels and an antechamber to house NEG strips and photon absorbers. Chambers in the doublet and multiplet sections, where intercepted bending magnet radiation is relatively low, will be built from simple tubular aluminum extrusions with a single water channel. Gauges, pumps, and valves for pump out and venting will be accommodated using crosses at five locations per arc. In addition, the system includes four RF-shielded gate valves and fourteen RF beam position monitor (BPM) assemblies which use a fixed feedthrough mounting block nested inside a pair of RF-shielded bellows.

In addition to a demanding set of performance criteria, there are a few aspects of the design that are somewhat unconventional and therefore warrant careful study. First, the design forgoes distributed pumping in some sections, exacerbating the challenge of maintaining sufficiently low pressures with such small chamber apertures. Second, while the approach to mechanical stability not unprecedented [2], it is atypical. Rather than attempting to control chamber temperatures so as to make motion of critically-aligned components like BPMs negligible, the design calls for each BPM to be mechanically decoupled from chambers using bellows. Third, because the vacuum system must be separable between modules for rapid installation and also to allow removal of BPMs without disassembly of magnets, a relatively large number of flange joints is required. To give confidence that the incidence of leaks will be sufficiently low, testing is needed to validate metallic flange joint designs and joining techniques, particularly those for dissimilar metals. Finally, the relatively large number of BPMs, bellows assemblies, and photon absorbers required to protect them requires a high degree of confidence in electrical impedance predictions for those components.

MOCK-UPS

Building and testing mock-up assemblies is helping to address many of the concerns described above. Two sets of mock-up activities are underway. The first involves fabricating, assembling, and studying a full sector arc of prototyped vacuum components. The second involves assembling integrated prototypes of vacuum, magnet, and support components for each of the four sector module types.

* Work supported by U.S. Department of Energy, Office of Science, under Contract No. DE-AC02-06CH11357.

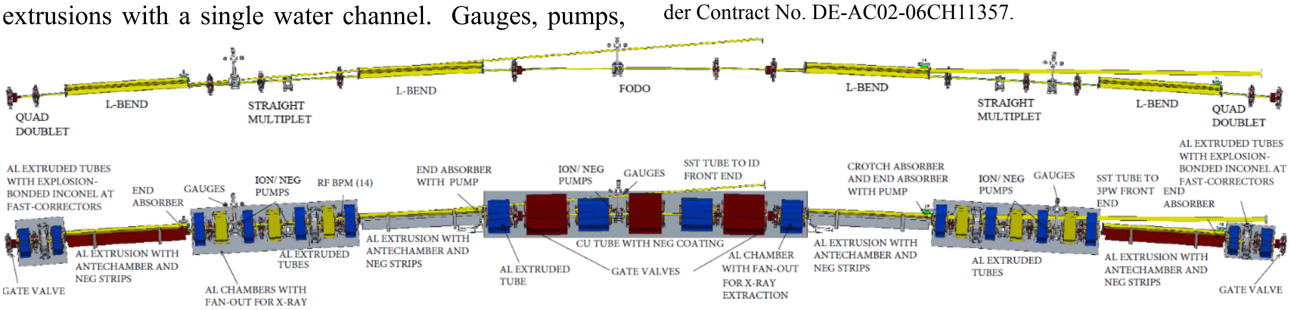

Figure 1: Layout of typical sector arc with and without magnets.

The mock-ups are, foremost, demonstrating that components can be built as designed. For example, one question, now answered, was if precision bending of aluminium extrusions needed for L-bend chambers could be readily accomplished (Figure 2). Additionally, mock-ups are helping to verify that: components can be easily installed to required specifications and will remain aligned under operational conditions, residual gas pressures will meet requirements, NEG coatings will tolerate the harsh thermal cycling expected with operation, RF-shielded bellows will tolerate repeated mechanical offsets, in-situ bake-out and activation of chambers will not disturb magnet alignment, and materials will not overly distort or shield magnetic fields.

Figure 2: Bending of an L-bend chamber extrusion.

Roughly half of the components required for the full sector mock-up have now been received and rigid support tables needed for mechanical stability measurements have just been installed. However, testing has already begun on an integrated mock-up of a multiplet section-type module (Figure 3). Assembly and alignment of vacuum components was found to be straight-forward with the exception of the BPM blocks which will require improved provisions for on-board position adjustment. In addition, magnetic measurements show no appreciable perturbation of quadrupole and sextupole magnet fields due to the presence of vacuum components.

Figure 3: Mock-up BPM in an integrated test assembly.

METALLIC JOINTS

Development of Automated Aluminium Welds

The four L-bend section chambers planned per sector require complex full-penetration profile welds which must be automated for consistent quality and control of underbead at the weld joint. Automated TIG welding of aluminium has been done for many years at ANL, but APS-U chambers require welding thinner walls than what has been done previously. Recently, welding of a 2.5 mm thick joint was demonstrated for mock-up L-bend chambers (Figure 4). Development will continue with the goal of achieving 2 mm thick joints.

Figure 4: Automated 2 mm thick aluminium profile weld.

Testing of Multicomponent Bonds

Sixty small, tubular chambers featuring twelve different types of multicomponent metallic bonds have been fabricated for testing which will help down-select amongst options for final designs and verify requisite robustness. Table 1 provides a listing of the UNS designations of the joined materials and the common abbreviation for the welding or brazing method used to bond them. Two of each type of the copper samples were also NEG coated to confirm adhesion of the coating to the bonded regions.

Table 1: Multicomponent Metallic Joints under Study

Tube Material	Transition Material	Flange Material.	Flange Bond
C10100	N/A	S31653	EBW
C15715	N/A	S31653	EBW
C10100	N/A	S31653	TB
C15715	N/A	S31653	TB
C10100	N/A	S31653	LBW
C15715	N/A	S31653	LBW
A96063	N/A	S31653	FRW
A96063	A92219	S31653	EXW
A96061	N/A	AL-unite [3]	TIG
A96063	A92219	N06625	EXW
N08904	N/A	S31653	TIG
N06625	N/A	S31653	TIG

Aggressive thermal and mechanical testing is being conducted to give confidence that the joints as designed and fabricated will be sufficiently robust for installation and machine operation. Each sample is thermally cycled twenty times between ambient temperature and 250 ˚C and then mechanically loaded by hanging a 5 kg weight from the end of the chamber, which applies both a lateral force and a torque of roughly 25 N-m. A helium leak check is performed after the loading operations to verify that no leaks exist above 1E-10 Torr-L/s. So far, the six copper sample types have been tested with no samples developing a measureable leak. The TIG-welded sample, however, was easily bent by the mechanical loading step, indicating that the copper was fully annealed by welding.

Metallographic studies are also being conducted for several of the suspect multicomponent joint types [4]. Sections are cut from sample chambers using a diamond wafering blade and subsequently mounted, polished, and etched. Stereo microscopy is then performed on the sections at magnifications of 25 and 1000 times. The investigations have helped to indicate where additional design development may be needed and are providing critical information needed to down-select amongst available joining options. As an example, imaging has indicated stress fractures in electron beam welded joints between stainless steel and copper which could cause the hermeticity of the joint to be compromised over time (Figure 5).

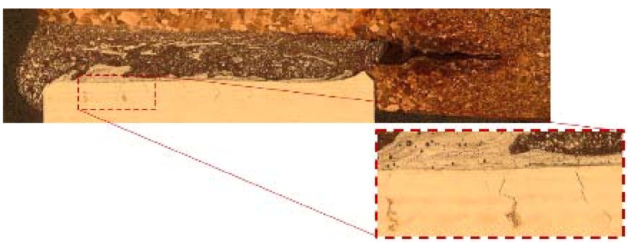

Figure 5: Stress fracturing in electron beam welds.

COMPUTATIONAL TOOLS

Considerable effort is being devoted to making best use of existing simulation software and to developing new computational tools where needed. Studies have been conducted using SynRad+ and MolFlow+ [5] with a wide variety of published photon-stimulated desorption (PSD) data to maximize the quality of predicted pressure profiles and to establish uncertainty estimates [6]. Numerical ray tracing programs have also been written to determine maximum allowed distances between the tips of photon absorbers and the design particle beam orbit and to calculate worst-case thermal loading on chamber walls under all possible beam steering scenarios [7].

PHOTON ABSORBER ALTERNATIVES

The high power density of radiation that will be generated in bending magnets and the limited space inside magnets for photon absorbers has stimulated consideration of alternative approaches to photon absorbers. One option is to employ heat pipes or vapor chambers which are highly customizable and which can transport heat much more effectively than a conventional water cooling circuit of the same size [8]. Another option is to utilize materials with longer absorption length to eliminate the need for surfaces that intercept the beam at grazing incidence and to minimize photon reflection, which can be a substantial source of PSD [9]. Computer simulations are allowing the potential benefits of such schemes to be quantified.

ELECTRICAL BENCH MEASUREMENTS

Electrical bench measurements are being used to establish a firm upper limit on what the resistive wall impedance due to NEG coatings will be and to also support computer simulations being used to determine impedance contributions and RF heating in BPMs, bellows, and gate valves [10]. Measurement on an uncoated copper chamber of S-parameters up to 50 GHz using a network analyzer has now been demonstrated (Figure 6). The chamber has since been NEG-coated and comparison measurements will be made soon. In addition, a separate test setup will be used to perform stretched wire-type measurements to confirm predicted resonant mode frequencies in prototyped BPMs, bellows, and gate valves.

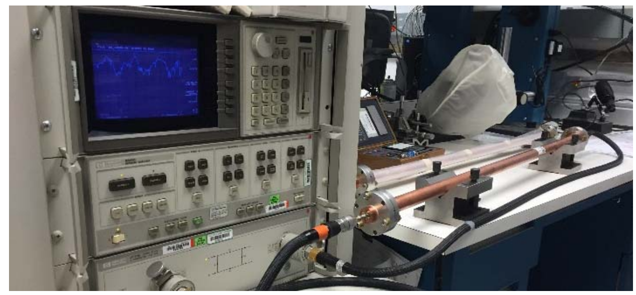

Figure 6: Network analyzer measurements on a copper vacuum chamber prior to NEG coating.

FUTURE WORK

Testing to measure impedance and electrically-induced heating of BPMs, bellows, and gate valves with particle beam is planned but details have yet to be established. Other work under consideration includes developing cost-effective methods to reduce PSD in aluminium vacuum chambers which may perhaps be accomplished using special coatings or by conditioning of surfaces with a glow discharge process.

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