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FINAL DESIGN OF NEG-COATED ALUMINUM VACUUM CHAMBERS & STAINLESS STEEL KEYHOLE VACUUM CHAMBERS FOR THE APS-U STORAGE RING

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Abstract

The APS-Upgrade storage ring features a diverse group of vacuum chambers which includes eight NEG (non-evaporable getter) coated aluminum chambers and two copper coated stainless steel keyhole-shaped chambers per sector (40 total). Each chamber contains a 22 mm diameter electron beam aperture; the keyhole chambers also include a photon extraction antechamber. The chambers vary in length of approximately 289 – 792 mm and fit within the narrow envelope of quadrupole and sextupole magnets. Each design is a balance of functionality, manufacturability, and installation space. An innovative CAD skeleton model system and ray tracing layout accurately determined synchrotron radiation heat loads on built-in photon absorbers and the internal envelope of the keyhole antechamber. Chamber designs were optimized using thermal-structural FEA for operating and bakeout conditions. The group of chambers require complex manufacturing processes including EDM, explosion-bonded metals, furnace brazing, and welding with minimal space. This paper describes the design process and manufacturing plan for these vacuum chambers including details about FEA, fabrication plans, and cooling/bakeout strategies.

INTRODUCTION

The APS-Upgrade project goal is to replace the 1.1 km circumference APS storage ring with a 6 GeV, 200 mA storage ring with a brightness above 4 keV. The new storage ring features NEG-coated aluminum vacuum chambers and pumping crosses that are a series of straight circular (Ø22 mm) aperture chambers that populate four of the five modules in the APS-U storage ring. An example of a pumping cross is shown in Fig. 1. In total, there are five chambers and three pumping crosses per sector (forty sectors total), varying in length 289 mm – 792 mm.

Figure 1: Rendering of the NEG-coated aluminum pumping cross.

The stainless steel (SST) keyhole chambers are a pair of vacuum chambers with extended outboard apertures as part of the overall scheme for extracting photons to the end users. The two chambers are 300 mm and 350 mm long with an example shown in Fig. 2. The NEG-Al chamber and SST keyhole chambers form the majority of the multiplet and double regions of the APS-U magnet lattice [1].

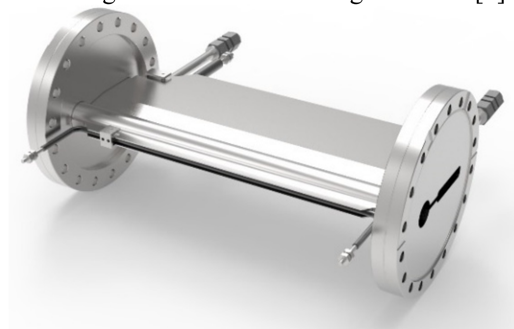

Figure 2: Rendering of a SST keyhole vacuum chamber.

Interfaces

The NEG Al chambers and SST keyhole chambers interface with the following systems: vacuum system, magnets, water system, and the electrical bakeout system. The primary design constraint of the chambers is to fit in the limited space envelope of the quadrupole and sextupole magnets as shown in Fig. 3 and Fig. 4.

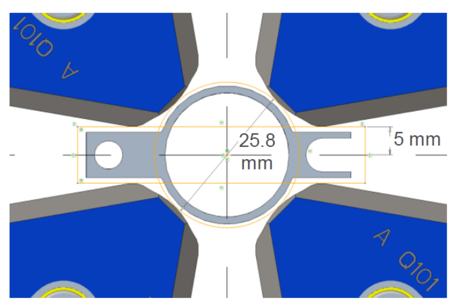

Figure 3: Cross-sectional view of an aluminum chamber within a quadrupole magnet.

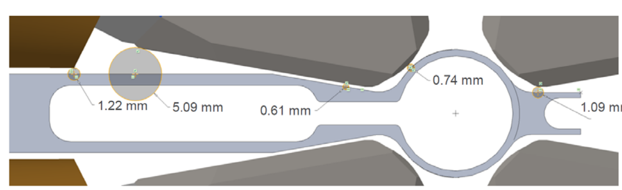

Figure 4: Cross-sectional view of a SST keyhole chamber within a quadrupole magnet.

Furthermore, the vacuum chamber space envelopes are limited axially and transversely as shown in Fig. 5. The water channels have to exit the magnet core and fit over the outboard photon extraction chambers with limited space.

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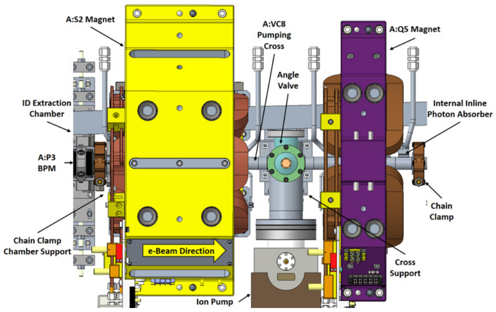

Figure 5: Top view of an aluminum pumping cross within a sextupole (left) and quadrupole (right) magnet.

The design also features an inboard slot for an electrical heating rod that runs along the length of the chambers for in-situ bakeouts. Both types of chambers contain an outboard water channel for cooling during machine operation.

Ray Tracing

A ray tracing layout of the APS-U storage ring was created in tandem with a CAD skeleton model. This allowed the ability to determine heat load footprints of synchrotron radiation as well as have the flexibility to adjust design parameters and allow the ray tracing to automatically update. This system approach influenced the design of many storage ring components to carefully adjust heat loads and shadow sensitive components [2].

Vacuum chamber material selection was driven by the resulting asymmetric photon distribution. Copper chambers are placed in regions intercepting 600 – 1000 W/m while aluminum chambers are placed in more collimated regions of approximately 0 – 160 W/m as a more cost effective system. With beam missteering, the maximum heat load intercepted by an Al pumping cross is approximately 98 W; further, the maximum heat flux experienced is 8.1 W/mm^2 along the inline photon absorber that is incorporated into the cross-section of the downstream chamber. The SST keyhole apertures were designed to allow synchrotron radiation to pass through without incidence onward to the extraction chambers as shown in Fig. 6.

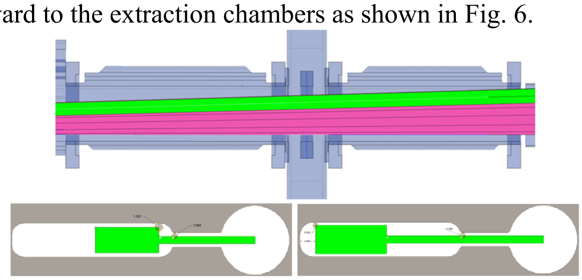

Figure 6: Top cross-sectional view of the ray trace through the keyhole chambers (top), upstream (left) and downstream (right) cross-sectional view of the beam envelope.

DESIGN

Prototypes

A series of aluminium vacuum chamber prototypes were developed for a storage ring vacuum system sector mockup. The designs consisted of a 6063 Al extrusion for the electron beam aperture and a 3 mm diameter water channel on the outboard side. Tubing is welded to the extruded body to route water outside of the magnet core space envelope. Furthermore, the design features Quick ConFlat (QCF) flanges machined from explosion-bonded 316L SST to 2219 Al. The APS-U storage ring system consists of multiple QCF flange joints held in place via a chain clamp. The QCF design requires less axial space than CF flanges and accommodates the narrow gap between APS-U magnets. Keyhole chamber design was developed in the post-prototyping phase [1].

Final Design

A cross-section of the final design of the NEG Al pumping cross is shown in Fig. 7. The crosses feature a standard chamber on the upstream end, a central body with vented slots, and a standard chamber with an inline photon absorber on the downstream end. Changes from the prototype phase include a larger 5 mm diameter cooling channel for turbulent cooling, a compact cooling layout, a planar shaped inline absorber, and slots to house electrical tubular heaters. The Al chambers are NEG coated after fabrication to reduce outgassing and add distributed pumping. Ion pumps and NEG-coated chambers provide the pumping for the conductance-limited vacuum system. The maximum bakeout temperature for the Al chambers is 150°C to avoid annealing but allow for NEG activation.

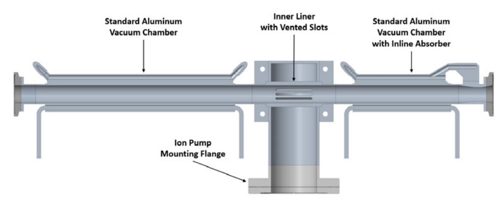

Figure 7: Top cross-sectional view of a NEG Al cross.

An overview of the 316LN SST keyhole chamber design cross-section is shown in Fig. 8. The design is a result of a balance between strength, magnet and beam envelope limits. Similar to other storage ring chambers, the design contains an outboard water channel, and an inboard heating channel. The chamber also features an additional outboard heating channel for supplemental heating due to the poor heating conductivity of SST. The chamber body is designed to be wire electrical discharge machined (EDM) with the flanges brazed to the body. The production design will feature electron beam welded flange joints. The surfaces that comprise the keyhole are to be copper plated.

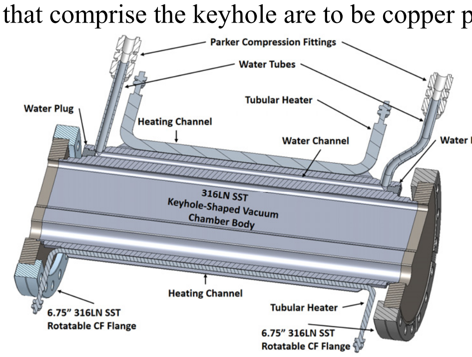

Figure 8: Top cross-sectional view of a SST keyhole chamber.

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FINITE ELEMENT ANALYSIS

Finite element analysis (FEA) was performed to evaluate the designs for operating conditions, bakeout, as well as buckling. To simulate the heat loads from synchrotron radiation, the FEA geometry was split along the beam footprint. Furthermore, the geometry was partitioned to transition from small element sizes along the beam to the rest of the chamber while using a sweep method. This strategy allowed a balance of control over the mesh quality and run time optimization. The larger pumping cross model incorporated submodeling to efficiently analyze.

A coupled thermal-structural FEA was utilized to simulate the conditions of operation and bakeout loading scenarios. For operation conditions, the heat flux from synchrotron radiation is imported along the beam footprint when applicable. Convective heat transfer coefficients were applied along the water channels with approximate magnitude of 10,000 W/m^{2}K. The temperature results of the pumping cross with the highest heat load (98 W) is shown in Fig. 9. The maximum temperature of 83.7°C is localized along the inline photon absorber.

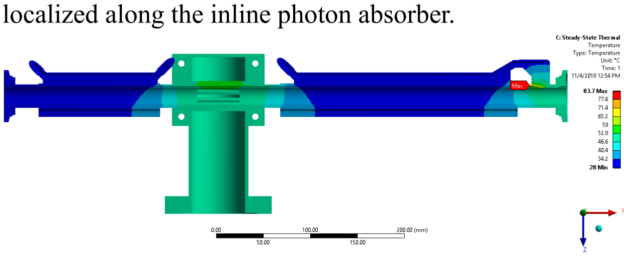

Figure 9: Top cross-sectional view of temperature results of the pumping cross FEA (max temperature 83.7°C).

For structural conditions, atmospheric pressure is applied to all external to vacuum surfaces, water pressure is applied to the water channels, and positional constraints are implemented to allow for thermal expansion without allowing free-body motion. The Von-Mises stress results for the pumping cross is shown in Fig. 10. Similar to the temperature results, the actual maximum stress of 46.3 MPa is local along the beam footprint. The maximum stress is extremely local along a corner and is a singularity.

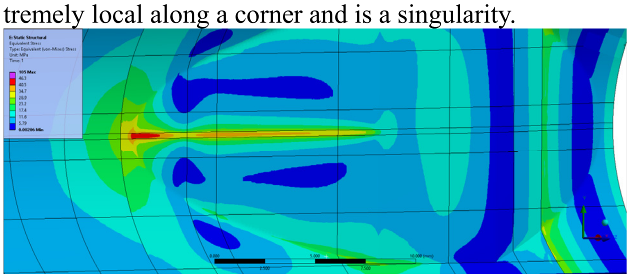

Figure 10: Von-Mises stress results of the photon absorber of the pumping cross FEA (max stress 46.3 MPa).

Similarly, the Von-Mises stress results for the SST keyhole chamber structural FEA is shown in Fig. 11. Note that a beam footprint is not applicable since the aperture fits the beam envelope without incidence. The maximum stress is extremely local along a corner and is a singularity. The actual maximum stress of 135 MPa occurs along the thin wall section of the chamber in the center along the interior (not shown).

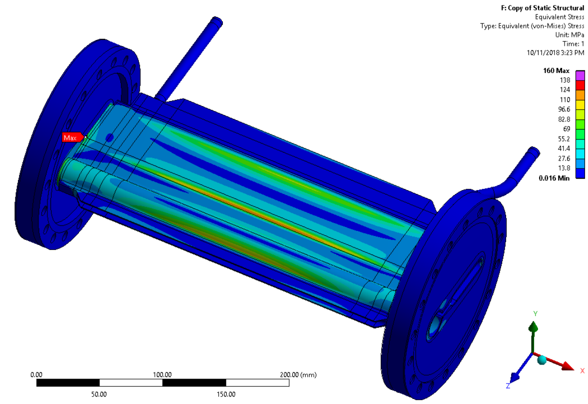

Figure 11: Von-Mises stress results of a structural FEA for a keyhole chamber (max stress 135 MPa).

Due to the irregular shape of the keyhole profile, a buckling analysis was performed to verify the chamber is capable of operating under UHV conditions. The result of the keyhole buckling FEA is shown in Fig. 12. The model is a 4 mm width (along the x-axis) sliver half-model. The first realistic critical load was found to be 328 atm, resulting in a 328 factor of safety.

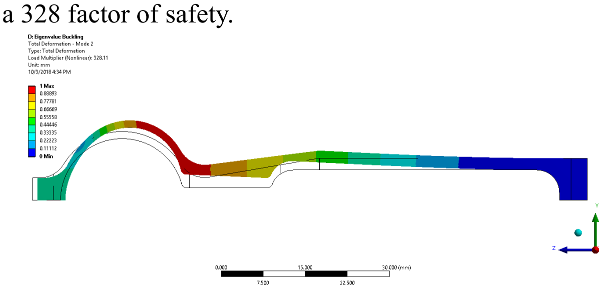

Figure 12: Critical load found to be 328 atm for buckling FEA.

CONCLUSION

The chambers presented is this paper have gone through extensive design, analysis, review, and bidding processes. APS-U is confident with the expected performance of these components. Future work for these projects include the procurement, fabrication, assembly, and installation process.

ACKNOWLEDGMENT

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REFERENCES

[1] J. Carter *et al.*, "Progress on the final design of the APS-Upgrade storage ring vacuum system," in *Proc. MEDSI'18*, Paris, France, June 2018, pp. 30-32. doi:10.18429/JACoW-MEDSI2018-TUPH04

[2] J. Carter, "3D numerical ray tracing for the APS-Upgrade storage ring vacuum system design," in *Proc. MEDSI'18*, Paris, France, June 2018, pp. 312-315. doi:10.18429/JACoW-MEDSI2018-THOAMA05