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APS UPGRADE INSERTION DEVICE VACUUM CHAMBER DESIGN*

J.E. Lerch†, T.J. Bender, O.K. Mulvany, M.E. Szubert
Argonne National Laboratory, Advanced Photon Source, Lemont, IL, USA

Abstract

A straight section vacuum system (nominally 5.363 meters long) has been designed for the APS upgrade project. This vacuum system will be used in straight sections equipped with hybrid permanent magnet undulators (HPMU). The vacuum system assembly consists of the insertion device vacuum chamber (IDVC), the vacuum chamber distributed support, and the photon absorber. Numerous functional requirements constrained the IDVC design. These constraints included incorporation of the beam aperture transition into the end of the aluminum vacuum chamber extrusion (storage ring aperture to IDVC aperture), thin walls (~600 microns) surrounding the beam aperture to allow for as small a magnetic gap as possible, and complicated weld paths to ensure a continuous beam surface to minimize impedance. Additionally, extensive finite element analysis (FEA) and ray tracing was performed to ensure that the chamber would not fail due to structural or thermal perturbations.

INTRODUCTION [1]

The APS-Upgrade (APS-U) project plan calls for the cur-rent APS 40-sector storage ring (SR) to be retrofitted with a new 6 GeV, 200 mA storage ring optimized for bright-ness above 4 keV. Thirty-one of the forty sector straight sections will be dedicated to Hybrid Permanent Magnet Undulators (HPMU) which will produce photons at various energies to ID beamline users based on their needs. Each HPMU straight section requires a vacuum system to ensure UHV continuity between the upstream and downstream sector arc vacuum systems.

The IDVC design must accommodate many functional requirements. Externally, the IDVC is spatially constrained by the HPMU's in all three directions (see Fig. 1). In the vertical direction (Y-axis), the chamber must fit within a minimum ID magnetic gap of 8.0 mm. In the longitudinal direction (Z-axis) the chamber must provide 5050 mm of space for the HPMU magnetic structures, phase shifters, and canting magnets (for canted HPMU configurations). In the transverse direction (X-axis), the chamber must provide adequate clearance for the width of the largest magnet structure. Internally, accelerator physicists limits the internal beam aperture height to a minimum of 6.0 mm and the aperture surface finish must have an RMS surface finish of <1 micron. The chamber must also provide an adequate antechamber so that enough pumping can be used to meet pressure requirements. Additionally, there must be a slot between the beam aperture and the antechamber to provide adequate vacuum conductance and avoid scraping synchrotron radiation from the upstream bending magnet, but not so large that the material in the wall yields while under vacuum due to wall thinning. The machine physics group also desires as few flanged connections as possible along the beam path to limit impedance during operation. Finally, the small difference between the minimum magnetic gap height and the minimum beam aperture height require the beam aperture to be aligned vertically (Y-axis) within a +/- 50 microns tolerance band and the chamber straightness to be +/- 100 microns across the length of the IDVC. The following is an overview of the IDVC design process with an emphasis on the design challenges encountered.

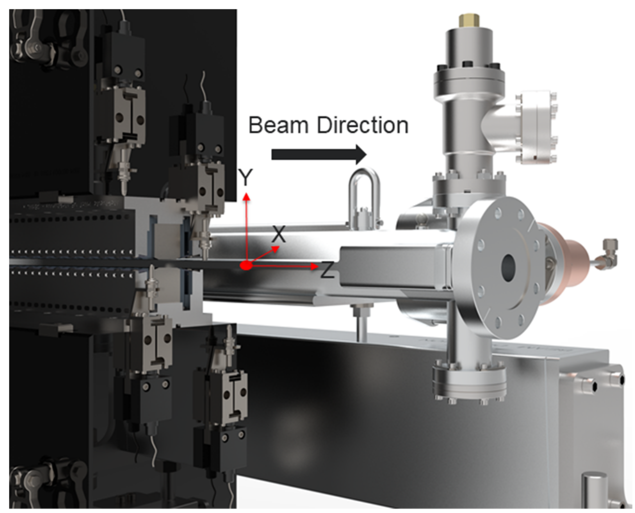

Figure 1: IDVC Assembly within HPMU structure. Coordinate system shown in red for reference.

IDVC EXTRUSION DESIGN

The IDVC is designed to be machined from a single 5.4-meter-long aluminum extrusion. The extrusion geometry (shown in Fig. 2) has three critical features: beam aperture, pumping slot, and antechamber.

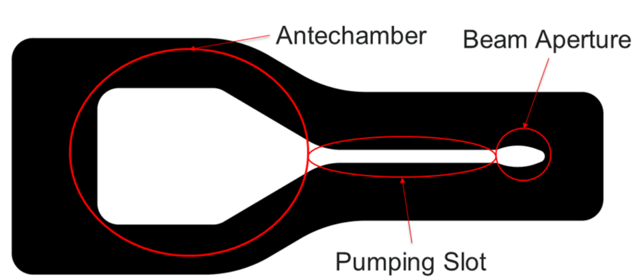

Figure 2: IDVC extrusion cross-section with critical features noted.

* Sponsor: Argonne National Laboratory
† Author Email: Jlerch@anl.gov

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All the critical features require tight tolerance bands to accommodate chamber performance requirements. An extensive discussion with our extruder was required so that the extrusion could be built ‘to print’ as opposed to ‘best effort’, where the repeatability of dimensions from extrusion to extrusion would be low. Once acceptable tolerance limits for the extrusion features were determined, nominal dimensions for critical features were set, finalizing the extrusion geometry. For example, the extruder could commit to a pumping slot height tolerance band of +/-0.3 mm. The nominal height of the feature was set based on this tolerance band so that synchrotron radiation would pass through the slot freely at the low end of the band (-0.3 mm), while at the high end the material in the surrounding wall would not yield (+0.3 mm). A structural finite element parametric study was performed to verify that the tolerance and nominal dimension was acceptable (see Fig. 3).

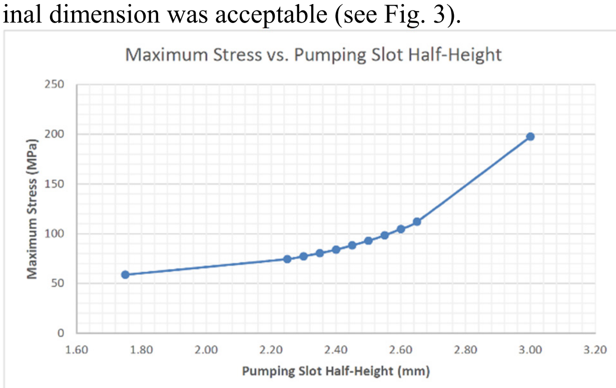

Figure 3: Parametric FEA study showing maximum stress as a function of the pumping slot half height.

The exterior dimensions of the extrusion were determined based on three main criteria: spatial limitations created by surrounding componentry, spatial needs for subcomponents welded to the extrusion, and spatial requirements for the beam aperture transition at each end of the extrusion. The primary accelerator component creating a spatial limitation on the IDVC is the HPMU magnetic structure. This structure allows the transverse length (X-axis) of the nose to be sized. On the outboard side of the extrusion (opposite the beam aperture) the extrusion is sized based on the largest flange to be welded to the IDVC after machining. Finally, the extrusion is made with enough thickness so that the transition from the storage ring aperture to the IDVC elliptical aperture can be machined into both ends, while still providing sufficient material for the welded end plate (explained further in the vacuum chamber machining and weldment section).

IDVC POST-EXTRUSION FABRICATION

The IDVC requires multiple machining processes prior to welding to ensure certain functional requirements are met. One of the most critical and difficult features to fabricate is the beam aperture transition at both ends of the extrusion (see Fig. 4). This transition allows a smooth geometric blend from the storage ring aperture (22 mm diameter round) to the smaller complex IDVC aperture (6.3 mm x 18 mm super ellipse) over a maximum length of 100 mm.

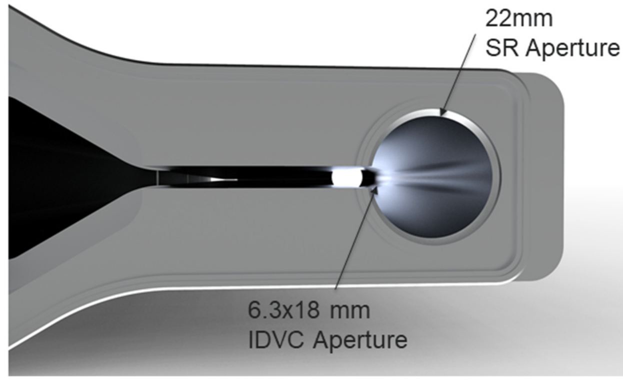

Figure 4: Beam aperture transition cone.

The method of fabricating the transition into the ends of the chamber is not common. Typically, the transition is a standalone component welded or brazed to the chamber. Two different fabrication methods were explored to determine the feasibility of the idea: plunge EDM and conventional machining. Figure 5L shows the cross section of the plunge EDM test piece while Figure 5R shows the cross section of the conventionally machined test piece. Both tests were successful and approved by both the APS machine physics group and the APS mechanical operations and maintenance group, however, the conventionally machined transition was significantly less expensive and produced a better surface finish.

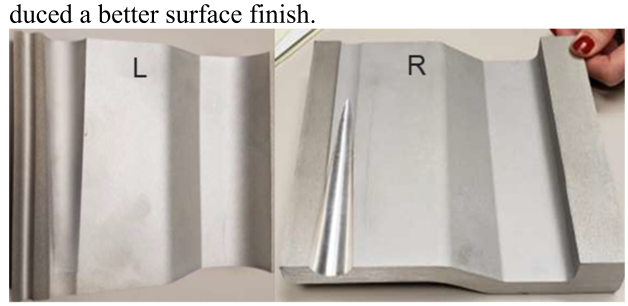

Figure 5: Plunge EDM (L) and conventionally machined (R) transition test piece.

Another critical feature machine on to the IDVC Is the ‘thin nose’ region. This region spans the central 5050 mm of the machined chamber and is the location of the thinnest wall. The wall thickness at the thinnest point is nominally 0.6 mm. Extensive analysis was performed in this area of the chamber to ensure that the chamber wall would not yield while under vacuum during bake-out (see Fig. 6).

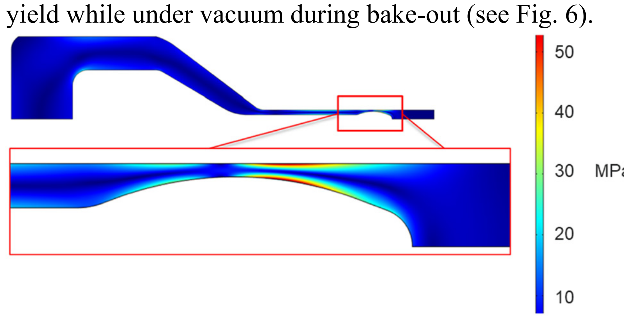

Figure 6: FEA of the thin nose region of the IDVC.

This area of the chamber is also subject to extremely restrictive tolerance. The flatness across the entire length of the top nose surface needs to be held at 50 microns. The

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bottom surface of the nose needs to be held parallel to the top surface within a 100-micron band.

The ends of the machined chamber are fabricated with a stepped weld profile so that an adjacent plate with a similar profile can lock into place prior to welding. This provides the manufacturer the option to perform the weld by hand or using a machine. Additionally, the weldment creates a seamless path for the beam through the IDVC from flange to flange.

Finally, there are multiple flanged ports welded across the length of the IDVC (see Fig. 7). These ports act as entries for vacuum equipment and a photon absorber.

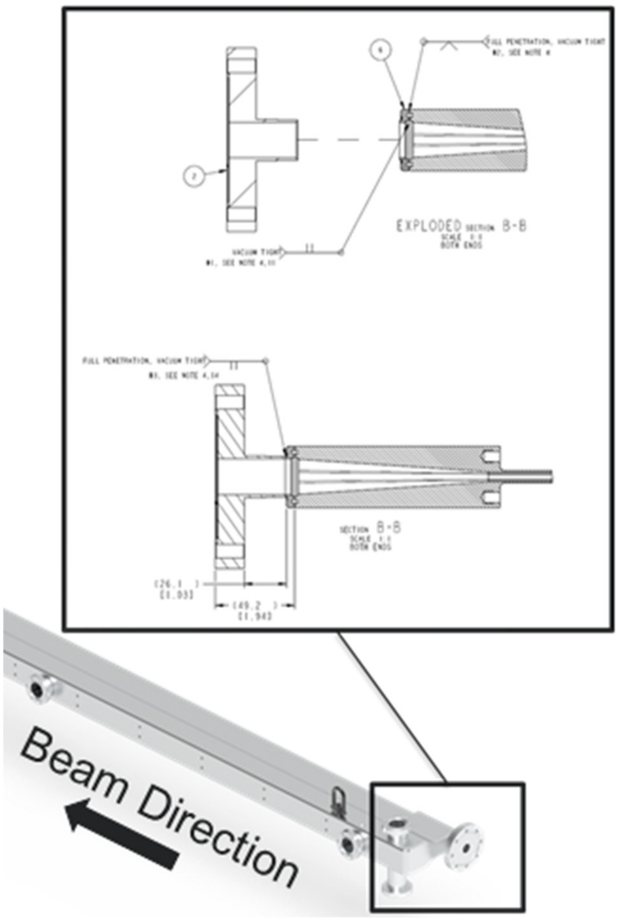

Figure 7: IDVC upstream end with interlocking plate weldment.

IDVC SUPPORT AND ALIGNMENT

The APS-U IDVC has a smaller cross-section (~2.5x's) than the current APS IDVC. Additionally, the alignment requirement for the APS-U IDVC is very challenging to achieve with conventional stand designs. The new IDVC support and alignment system (see Fig. 8) uses a distributed support across the length of the IDVC to minimize regions where uncorrectable deflection may occur. Chamber position can be corrected at 15 points across the length of the support. Finally, the ends of the support are designed to tie into the concrete plinths at the upstream and downstream end of the straight section. These locations provide additional degrees of freedom for positional correction, though at a resolution only used for rough alignment prior to bake-out. All final aligning will be accomplished using the multiple points of adjustment across the length of the support.

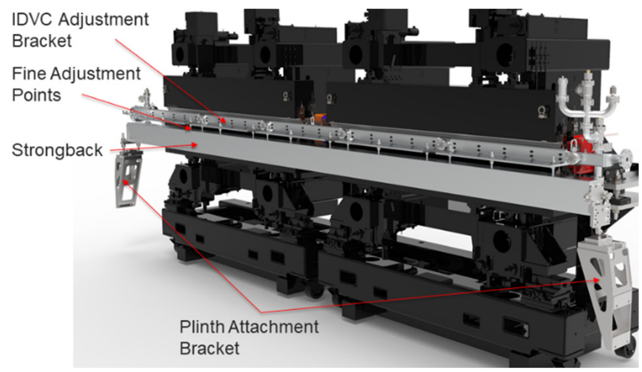

Figure 8: IDVC support and alignment system.

CONCLUSION

A straight section vacuum system has been designed for the APS upgrade project. The vacuum system allows for seamless beam transit across the entire ~5.36-meter length of the IDVC. Additionally, the design incorporates many newly proven design ideas such as incorporating long transitions into the ends of the IDVC. These new features, along with a distributed support and alignment system, allow the design to meet the numerous challenging functional requirements constraining the IDVC design.

ACKNOWLEDGMENT

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REFERENCES

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